(2)

COMPARISON OF QUANTITY VERSUS QUALITY USING PERFORMANCE, RELIABILITY, AND LIFE CYCLE COST DATA. A CASE STUDY OF THE F-15, F-16, AND A-10 AIRCRAFT

THESIS

David C. Merker
First Lieutenant, USAF

AFIT/GSM/LSQ/85S-23

DEPARTMENT OF THE AIR FORCE
AIR UNIVERSITY
AIR FORCE INSTITUTE OF TECHNOLOGY

Wright-Patterson Air Force Base, Ohio

AFIT/GSM/LSQ/85S-23

COMPARISON OF QUANTITY VERSUS QUALITY USING PERFORMANCE, RELIABILITY, AND LIFE CYCLE COST DATA. A CASE STUDY OF THE F-15, F-16, AND A-10 AIRCRAFT

THESIS

David C. Merker
First Lieutenant, USAF

AFIT/GSM/LSQ/85S-23

Approved for public release; distribution unlimited

The contents of the document are technically accurate, and no sensitive items, detrimental ideas, or deleterious information are contained therein. Furthermore, the views expressed in the document are those of the author(s) and do not necessarily reflect the views of the School of Systems and Logistics, the Air University, the United States Air Force, or the Department of Defense.

AFIT/GSM/LSQ/85S-23

COMPARISON OF QUANTITY VERSUS QUALITY USING PERFORMANCE, RELIABILITY, AND LIFE CYCLE COST DATA. A CASE STUDY OF THE F-15, F-16, AND A-10 AIRCRAFT.

THESIS

Presented to the Faculty of the School of Systems and Logistics
of the Air Force Institute of Technology
Air University
In Partial Fulfillment of the
Requirements for the Degree of
Master of Science in Systems Management

David C. Merker, B.S.
First Lieutenant, USAF

September 1985

Preface

The purpose of this study was to investigate the quantity versus quality issue and to design a cost-effectiveness model which incorporated mission effectiveness, readiness, and life cycle costs. The results of this thesis should help defense decision makers with weapon decisions which involve quantity versus quality issues. The methodology that was developed, also has general applications to other cost-effectiveness comparisons.

During this research I have received a great deal of support from many people. I would like to thank my faculty advisor, Lt Col John Long for the many hours he devoted to this effort. I would also like to thank Dr. William Mauer for his help and technical advice on the thesis. Finally, I wish to thank my wife, Kathleen and sons, Jim and Daniel. Without their support and understanding throughout the past year, the thesis could not have been completed.

David C. Merker

Table of Contents

Page

List of Figures

List of Tables

Abstract

The primary emphasis of this research effort has been to investigate the quantity versus quality issue and to design a cost-effectiveness model to aid in evaluating it. This model incorporates mission effectiveness, readiness, and life cycle costs. The research effort was hinged around a case study comparison of the F-15, F-16, and A-10 aircraft. These aircraft were chosen because they represented varying system complexities and were used as surrogates to high, medium, and low complexity respectively. The comparisons made in this thesis were intended to demonstrate the usefulness of using aircraft effectiveness, readiness and cost data in a mathematical cost-effectiveness model.

The methodology that was followed, involved combining multi-attribute value theory, aircraft readiness data, and aircraft life cycle cost information. The result of this approach was a series of cost-effectiveness ratios, and a cost-effectiveness curve which incorporated the three close air support aircraft. The cost-effectiveness curve provided the costs, adjusted by both effectiveness and readiness values. The results of this research indicate that the approach used to develop the cost-effectiveness model does provide a quantitative way to evaluate the problem of quantity versus quality.

COMPARISON OF QUANTITY VERSUS QUALITY USING
PERFORMANCE, RELIABILITY AND LIFE CYCLE COST DATA.
A CASE STUDY OF THE F-15, F-16, AND A-10 AIRCRAFT

I. Introduction

The costs associated with the development, production, and deployment of new weapon systems are increasing at an accelerated rate. Defense planners are constantly confronted with the problem of developing systems that provide the required national defense for the lowest price. Increasing life cycle costs and production times are having a significant effect on the readiness of the United States armed forces, especially in the areas of availability and supportability (14:70). Two types of weapon system design approaches that are frequently evaluated during the conceptual phase are: 1) those that utilize superior system performance and 2) those that use increased unit numbers to meet mission requirements. In many cases either approach can provide the required defense need; however, it is often debated which one is the most cost effective.

The debate between the two weapon design approaches has been voiced in many ways. Two of the more popular ways are quality versus quantity and technology versus numbers. In

both of these cases the basic underlying question is the same. Is it more cost effective to buy fewer high technology weapon systems or a large number of less sophisticated weapon systems?

In addition to the issue of weapon system costs, other aspects of the Quantity versus Quality problem must be addressed. One of the more important issues is the impact of quantity versus quality decisions on national security. The U.S. has followed the policy of creating weapons with superior quality. United States officials and planners believe that superior fighter quality will be the dominant factor in future conflicts. It is commonly known, however, that with regard to quantity versus quality the U.S.S.R. has taken an approach opposite to the U.S. The U.S.S.R. has committed themselves to creating a large force with emphasis on superior numbers. Because of these different fighting philosophies, and the unproven nature of each sides assumptions, it is imperative that the quantity versus quality issue be closely examined.

Problem Statement

There are two major system design philosophies that can be used to meet the required defense needs. The first type of design strives for advanced capability and requires fewer individual numbers to perform a mission. The second type of approach emphasizes simpler weapon design and

relies on greater numbers of units to meet the mission threat. To date the research methods that have been used to quantify the costs associated with these two approaches have not collectively taken into account performance, reliability, and life cycle cost data. Because of this, the information obtained from previous studies of quantity versus quality do not provide an adequate basis of comparison of the two design approaches.

The information and data obtained from the comparison of quantity versus quality, using a systematic mathematical approach combining performance, reliability, and cost data, will provide defense managers with a reproducible, less biased decision tool. A mathematical approach will also provide the manager with more accurate information on the costs and performance factors associated with the two different system design approaches.

Background

A review of the work done on quantity versus quality has revealed a great deal of activity. Past efforts to examine the question appear to have taken one of three approaches.

The first approach found in the literature, looked at the issue of quantity versus quality from a "gut" feel position. These reports usually looked at the problem from the point of view of either a strategic/tactical or supply

availability position. The reports taking this path have tended to rely on more subjective analysis rather than rigorous mathematical models or computations. An example of this type of approach is William S. Lind's article in the September - October issue of <u>Air University Review</u> titled "Quantity Versus Quality Is Not The Issue". In this article Lind examines "typical" comments made by individuals in favor of quantity. Without any computations or rigorous analysis Lind concluded that:

> The choice is not between quality and quantity. It is between technological quality and tactical quality with quantity. We can choose between a small number of relatively ineffective weapons or a larger number of effective weapons. The real question is, why does the defense establishment prefer the former? (21:88)

In this case Mr. Lind made personal observations about the issue of technology versus numbers, but did not use any hard facts or data to back up his analysis. Because of his nonrigorous approach to the problem his conclusions can be easily disputed by anyone with another point of view.

The second type of report written on this subject tends to focus on the issue from the standpoint of life cycle costs only. These research reports examined life cycle cost issues of the problem using a rigorous cost analysis. The cost analysis reports generally evaluated the two types of system approaches side by side without regard to system performance or reliability. An example of this approach is a report done by the BDM Corporation for the Aeronautical

Systems Division's (ASD) Mission Analysis directorate in 1981. The report is titled "An Examination of the Affordability of Increased Numbers of Less Complex, Less Capable Aircraft". In this report the objective was to:

> Estimate the numbers of aircraft that could be obtained by making trade-offs among procurement costs, personnel costs, and maintenance costs, considering historical budget constraints. (3:8)

The report provides an overview of the effects of different costs on possible aircraft numbers. BDM's final conclusion and recommendation to ASD was that "selections considering quantities and qualities of forces must assess relative effectiveness as well as costs" (3:87).

The final type of research available on the subject of quantity versus quality evaluated the question using scenarios to compare simple and complex systems. The conclusions that appear in the literature for this type of approach have been that simpler systems don't have the capabilities of more complex systems.

An example of this type of report is " Austere vs. Capable Aircraft Effectiveness Analysis" done by the Deputy for Development Planning Directorate of Mission Analysis of the Aeronautical Systems Division. The analysis used a simulation model and compared the estimated numbers of A-10 and F-15 aircraft that could be procured for equal life cycle costs. This study appears to be the best comparison used to date; however, it also neglects any reliability or availability factors.

All three approaches take a limited view of the question of quantity versus quality. The work done in the area of simulation and quantitative research has been primarily initiated by the mission analysis directorates of the Air Force Systems Command (AFSC). Unfortunately the work done and methods used by these directorates are very time consuming and are only used to evaluate systems on a one time exception basis. The time and costs associated with these studies are prohibitive, and not cost effective for other than major weapon system decisions.

An added shortcoming of the quantitative reports produced by AFSC is that the computer simulation models do not provide the defense manager with the insight into the contributions of the individual aircraft characteristics. The simulations also can not provide a view of the interactions and synergisms associated with the collective system's performance characteristics.

Scope

This research effort used only generally available aircraft performance information and is unclassified. The techniques and models used and developed by this research do not compare all the possible performance or availability characteristics of the representative aircraft, nor does it examine all possible aircraft combinations. Only the Close Air Support (CAS) mission was considered. The comparisons

made in this thesis are intended to demonstrate the usefulness of combining aircraft effectiveness, readiness, and cost data, in a logical mathematical model. This logical mathematical model in turn is designed to help defense managers to cope more effectively with problems involving quantity versus quality.

Research Objective

The objective of this research effort was to investigate the quantity versus quality issue and design a cost-effectiveness model which incorporated mission effectiveness, readiness, and life cycle costs. The results of this thesis should allow a defense manager to more adequately compare aircraft systems with advanced capability versus systems that rely on greater numbers. The methodology that was developed by this research has general applications to other decision analyses involving the quantity versus quality issue.

Specific Research Questions

Specific research questions that were investigated in support of the objectives:

1. What are the aircraft attributes that most substantially impact the Close Air Support (CAS) mission? This question was directed to Maj Jack Shafer of the Tactical Air Command (TAC) Combat Analysis Branch (TAC/DOP). Major Shafer was the decision maker for the thesis.

a. What are the individual performance specifications of the representative aircraft for the attributes selected in research question #1?

2. What is the Multi-Attribute Value (MAV) function for the attributes provided? This question is focused on determining the rank order effectiveness of the representative aircraft in the Close Air Support role.

3. What is the effectiveness ratio of one aircraft to another, from the standpoint of performance? This will be accomplished through a manipulation within the MAV function to determine the effectiveness ratios of the representative aircraft.

4. What are the "Steady State" readiness figures for the aircraft? The steady state readiness numbers will allow the effectiveness ratio determined from research question #3 to be normalized with regards to aircraft reliability data.

5. What are the estimated Life Cycle Costs (LCC) for the representative fighter aircraft? The objective of this question is to determine both the variable and fixed costs associated with the three different fighter aircraft. To allow an accurate comparison, the LCC data obtained for each aircraft will be derived in the same way and include the same types of data.

6. How appropriate is the application of the methodology used for this research to other mission

decision analyses? The research performed in this thesis should be generally applicable to other quantity versus quality problems.

Assumptions

Four major assumptions will be followed in this research:

1. All weapon systems that are compared have the capability of performing the mission given sufficient numbers.

2. Risks associated with the procurement of advanced systems will be included in the cost of procurement.

3. Lead time and critical materials required to build systems will not be considered as a factor of evaluation.

4. Increased numbers involve increased resources (both manpower and materials). These increased resources will only be viewed from the standpoint of additional cost in the mathematical calculations.

II. Literature Review

Introduction

The United States government has recognized that the cost of acquiring, fielding, and maintaining weapon systems is growing at an astronomical rate. The increase in life cycle costs and production time is ultimately effecting the readiness of the United States armed forces in the areas of availability and supportability (14:70). This trend has caused the Department of Defense and the military servic s to institute programs to reduce life cycle costs and increase productivity.

In light of these trends the United States has the increased burden of developing effective ways to achieve the best nation defense. There are three ways that commanders and defense planners can develop and deploy air power today: quantitatively, qualitatively, and a combination of both (1:2). Each of these three approaches has advantages and disadvantages. Traditionally the United States military leaders have followed one exclusive path.

> The United states has emphasized quality over quantity in its efforts to counter the threat posed by numerically superior conventional Soviet forces. (19:4)

The issue of quantity versus quality has been around for years, and many debates have occurred. In 1916 Frederick William Lancaster published a study on combat effectiveness, looking at the combat issue from the stand point of quantity versus quality.

> Lancaster's law state[d] that the combat effectiveness of a force depends on the quality of the weapon systems multiplied by the square of the size of the force. (22:100)

This is one of the first formal attempts to try to quantify the problem for the purposes of defense planning and strategy. Since that time different policies have been developed and tried within the Department of Defense.

Recently the emphasis on the issue of quantity versus quality has increased. On 15 May 1979 The House Armed Services Committee released a report that addressed the problem of quantity versus quality.

> The committee recommend[ed] that the Enhanced Tactical Fighter (ETF) lead in program be terminated. Instead of looking at aircraft that are more complex, more expensive, and more difficult to support and maintain, the committee believes that the Air Force should expend some effort looking at less complex, less expensive aircraft concepts that will increase readiness and increase numbers. (28:87)

In order to understand the implications of the quantity versus quality issue it is important to know the many factors involved with the question. The only way to make an appropriate decision is to be aware of the trade offs.

Advantages of Large Numbers of Simpler Aircraft

The advantages of large numbers of simpler aircraft can be viewed in two ways. The first is the strengths associated with simplified design. The second is the effect that increased numbers have on readiness and war fighting capability.

> Simple aircraft offer the advantages of low cost [per aircraft], high manuverability, small size and lethality... they have the capability to augment combat forces under conditions that would limit the effectiveness of large sophisticated aircraft. (16:10)

The use of less sophisticated hardware to increase reliability and system performance has been a very practical approach to improve weapon effectiveness. "Most industrial specialists agree that simplicity is probably the single most important factor in achieving increased reliability" (14:75). Success of several programs can be directly attributed to the simplicity of their system/subsystem design.

An example of a successful application of the simplified system approach is the Hughes APG-65 multimode radar system for the F-18 aircraft. The APG-65 has approximately 15,000 parts and has achieved a Mean Time Between Failure (MTBF) rate of approximately 110 hours. A similar Hughes multimode radar selected for the F-4 aircraft with over 28,000 parts has only achieved a MTBF rate of approximately 10 - 15 hours (14:75). In this case

fewer parts and a less sophisticated design have improved the MTBF ten fold. Another example of the use of less sophisticated hardware is "the General Electric F404 engines powering the F-18 [which] have approximately 14,000 parts compared to 22,000 parts in the earlier General Electric J79 engine ...the Mean-Time-Between-Failures on the F404 engine is about five times that of the J79 ..." (14:75).

In both of these cases the less sophisticated system design provided the required performance with greater reliability. Simplified design is good for a number of reasons. Usually the most important reason, to the manager, is the short term savings in the design and production costs. Another positive factor that must be considered is the effect increased reliability will have on lowering the operational and support costs in the future (12:2).

The second major advantage is that availability of larger numbers of aircraft is often useful to tactical commanders. By increasing the physical numbers of aircraft available for deployment, the range of influence of the tactical forces can be substantially improved. Another consideration is the effect greater numbers of aircraft will have in a protracted conflict environment. Losses

must be expected in combat, however, the more aircraft available to fight, the less the impact of individual losses. That is to say that if a force of two is available to fight and one is shot down, the loss results in a 50% reduction of the fighting force. However if a force of ten was initially available, five individual units would have to be eliminated in order to reduce the force by 50%.

A simplistic weapons approach was used quite extensively in the Vietnam War by the Vietcong, who used simple materials found in the field as crude weapons. For example, the Vietcong would construct crude mortar projectors out of pipes and bamboo. These weapons were very inexpensive and simple to build. The individual units were not very accurate, but, because of the large numbers of units available, the overall system was very successful in meeting its objectives. In this case the overall system was very effective even though no one unit was required to meet any stringent performance criteria.

Disadvantages of Large Numbers of Simpler Aircraft

The major fault with the less complex approach to design is that even very simplistic weapon systems cost substantial amounts of money when they are produced and deployed in large numbers.

Larger numbers of austere [less complex] aircraft can be procured versus a more capable aircraft for a given life cycle cost. However, the significant increase in manpower (pilots, maintenance, etc) must be satisfied, the resulting basing and sheltering problems must be resolved, and existing force structure constraints must be relieved. (9:4)

Large numbers of individual units can also cause a great deal of strain on the spares and support pipelines. An example of the effects of this strain can be illustrated using historical data from the F-14A and F-111A aircraft programs. In both of these programs there were not enough spare parts available to meet the operational requirements. Commanders were forced to remove working parts from downed airplanes and use them to repair others. This is referred to as "maintenance cannibalization" (14:44).

. . . on a per-100-sorties basis in fiscal year 1979, that process [cannibalization] went as high as 69.6 [%] for the Grumman F-14A and 39.4 [%] for the General Dynamics F-111A and F-111D . . . (14:44)

This type of maintenance practice ultimately reduces the overall availability of aircraft because the cannibalized planes eventually develop other non-use related maintenance problems. This type of situation can be avoided by good initial planning by the acquisition decision makers.

Advantages of Smaller Numbers of More Complex Aircraft

The United States government has prided itself on its ability to produce the 'best' weapon systems in the world and in providing a strong defense for the U.S. and her allies.

> Proponents of quality fighters state that technology improvements are imperative to insure more lethal and predictable results and to prevent recurrence of past mistakes in future combat. (16:1)

The decision to follow a technological quality design approach is often made at very high levels of government. One of the major considerations addressed by Department of Defense planners and managers are the military personnel responsible to act for the U.S. in time of conflict. The human resources of the United States government are highly regarded and not considered as 'generally expendable'. The deployed weapons are built with the thought in mind that the Armies should have the best equipment possible, and this is achieved through the use of state-of-the-art technology. Other governments, such as the USSR, consider individuals as well as weapons as expendable and that overwhelming numbers will be the deciding factor in future conflicts.

Because of the advanced capabilities associated with high technology programs, it is believed that fewer numbers are necessary to achieve the desired defense need. It is often thought that fewer numbers of individual units are easier to maintain (16:4).

> Air Force planners must also address manageability of forces as still another justification for sophisticated aircraft. The probability of limited forward operating locations in future combat zones suggests that fewer aircraft incorporating the latest technological advances will be easier to manage and control in at least three areas. In the communications area... In the ground support area... Finally, fewer recoveries and launches at forward operating locations. . . (16:4)

In the current era of super power cold war, it is evident that the USSR is making strives toward military improvement. In addition to the efforts of Russia to maintain a quantity force, their advances in technology are becoming very noticeable.

> It is my impression that the Soviets will viscerally prefer quantity over quality, but that they will soon (if not already) match our technological capabilities ... In no case would I expect them [Soviets] to accept a numerical inferiority. (27:6)

With this thought in mind, it appears that any lessening of the US technological advantage could tilt the super power scale decisively in the direction of the Soviet Union.

Disadvantages of the High Technology Design Approach

In a highly technological world the use of sophisticated system designs to meet new and existing threats is common. The problem with this type of thinking is that some system improvements are developed and implemented without any real cost effectiveness comparisons with existing or 'older' technologies.

> In nearly every weapons system, designers have pushed technology as the solution to American military problems, without distinguishing between . . . innovations that simply bread extra layers of complexity and those that represent dramatic steps toward simplicity and effectiveness. (13:21)

The advancement of the weapon technologies used throughout the world has increased the need for high technology weapon systems in the United States. The advantages and disadvantages of high technology, with regard to cost, schedule, performance, and reliability, are of constant concern to the program manager during the acquisition of weapon systems. Many experts in the field of weapon system acquisition agree that:

> Complexity leads to: poorer reliability, lower availability, [and] poorer maintainability, which results in low productivity, higher operating costs, increased maintenance load, and need for highly trained personnel. (9:1)

Many of the new advanced weapon designs rely exclusively on the use of state-of-the-art integrated microcircuits. The microcircuit technology has improved the actual number of processes that a system can perform; however, the initial reliability of new microcircuit technology has been, historically, less than acceptable. The increased use of modern microcircuits has sharply decreased the reliability and performance of new weapon systems. In fact, a technical survey in Aviation Week and Space Technology even stated:

> ... in the past decade demands for increased performance became the primary driver of design efforts and the consistency with which a system achieved this performance often became a inverse function of it's sophistication and operational capability. (14:42)

The ARC-164 military radio illustrates the reliability problems associated with 'pushing the state-of-the-art'. It required almost five generations of design iterations before it met the reliability standards required by the Army (14:81). This redesign iteration was very expensive and created substantial scheduling problems. This type of design problem is generally known and is not uncommon. In many cases, after several generations of design improvements, the system no longer meets the state-of-the-art requirements initially required.

One method used by design engineers to achieve greater reliability with the new generation microcircuits is known as redundant design. Redundant design creates multiple electronic pathways within a system. This decreases the reliability requirements of any one part while increasing the operational reliability of the overall system. The major problem with redundancy is that it requires very expensive and time consuming engineering design. This increases the cost of Research and Development (R&D) and, in most cases, expands the schedule. The redundant design approach is generally scrutinized by defense program managers because it increases the front end costs of a program (17:23).

An added consideration that must be made by the program manager regarding high technology weapon systems is whether or not they will require specially trained personnel or special facilities to maintain them. This must be considered by defense managers and planners due to the additional costs and planning required for the system.

The Defense Manager's Responsibilities

The defense program manager has the overall responsibility of implementing the applicable regulations and directives, and assuring that the system meets certain performance criteria. Trade studies must be performed and reviewed to determine the different design approaches that will satisfy the regulations, directives, and performance requirements. DoD Directive 5000.40 rates the operational availability of a system as important as its operational performance. This directive requires defense program managers to thoroughly consider system reliability and performance factors.

In the area of system performance and reliability, the program manager must insure that the system design meets a predetermined availability and performance criteria. This can be achieved by a number of different design approaches (12:3). The manager must compare factors, such as life cycle costs, producibility, maintainability, supportability, and mission need, so that the best design methodology can be found.

The refinement of requirements from general system specifications to specific system specifications is accomplished through a systematic review of cost, schedule, and performance trade offs. One of the initial trade offs that must be explored is the affect of different performance requirements on the acquisition of the total system. This type of trade study was performed on the F-15 aircraft to determine the optimum thrust-to-weight ratio of the engine to the air frame. The trade study initially determined that an 8:1 thrust-to-weight ratio from an F-100 Pratt & Whitney engine would present more reliability problems than the existing 5:1 and 6:1 ratio engines. When the cost, schedule, and performance trades were all completed and analyzed, it was determined that the 8:1 ratio was needed to meet the stringent performance requirements. This decision increased the performance of the aircraft at the expense of reliability and possibly availability (14:44).

Summary

There are many factors that influence the acquisition of a new weapon system. Defense planners and managers must look at all the different elements of the problem. There is a danger if only one of the elements is considered without consideration of the others.

> If reliability [for example] has the maximum priority, the designer will use only the highest quality, expensive parts. Furthermore he will normally build equipment larger and heavier since larger and heavier equipment tends to be more reliable. He will also need to trade off performance, survivability, and human factors. (20:26)

The aforementioned passage illustrates why weapon decisions must be made with the total system requirements in mind. The program manager must always trade off the advantages and disadvantages of all the factors involved in a program before making a decision. The emphasis must always be on the total system to obtain the best mix of possible design alternatives and life cycle costs.

> The advantages [found with less sophisticated aircraft] of predicted higher reliability, fewer aircraft systems, and less complex maintenance must be weighed against the disadvantages of possible increases in maintenance, supply, and servicing transactions at base level. (16:13)

The decisions made during the development and production phases of a system are very complex and interdependent. Design decisions made during the acquisition phases will effect both the performance and total life cycle costs of a system. These decisions must be carefully considered because of the military importance of these programs and the limited funds available. The cost effectiveness studies used in the procurement of weapon systems ultimately determine the total number and capabilities of the weapon systems the United States can

deploy. In an ever changing world, the dollars saved, or well invested today, will be the cornerstones of a strong national defense tomorrow.

III. Design Background and Specific Methodology

Background

A specific set of procedures used to develop a mathematical approach to the problem of quantity versus quality is presented. The method draws upon the concepts of traditional cost-effectiveness analysis combining mission effectiveness, readiness and life cycle cost data into a quantitative decision tool. In order to appreciate the selection and application of the techniques used in this thesis, it is necessary to understand the foundations and general characteristics of cost-effectiveness techniques.

A cost effectiveness analysis "is any analytic study designed to assist a decision maker identify a preferred choice from among possible alternatives" (23:2). The general cost effectiveness model, as shown in Figure 1, displays the basic sub-elements contained in a cost-effectiveness analysis. The sub-elements of the model are: (23:5)

1. The Objective - The policy or course of action that the organization is attempting to maximize or minimize.

2. The Alternatives - The set of possible solutions that can be employed to achieve the desired objective.

3. The Costs - The amount of penalty (cost or resource) associated with the choice of a alternative.

4. A Model - The introduction of artificial factors with the assumption that the factors are representative of the real external environment.

5. The Criterion - The predetermined measurement method that will be used to judge the alternatives.

The method that was used for this thesis is very similar to the analysis structure shown in Figure 1. The only major difference between this thesis and Figure 1 is that system cost will be incorporated into the effectiveness calculation. All the basic sub-elements are still present and are presented below.

The Objective

The objective of this research has been defined in Chapter 1. In essence the objective was to determine the lowest cost required to meet mission requirements, given the constraint that aircraft with different capabilities are to be compared.

The Alternatives

The alternatives evaluated in this research were the different aircraft available to meet a desired defense mission. These aircraft meet the defense needs with the use of either high, medium, or low technology. As mentioned in Chapter II, there are many design approaches and varying technologies that can be employed to achieve the same mission result. This thesis only looked at a

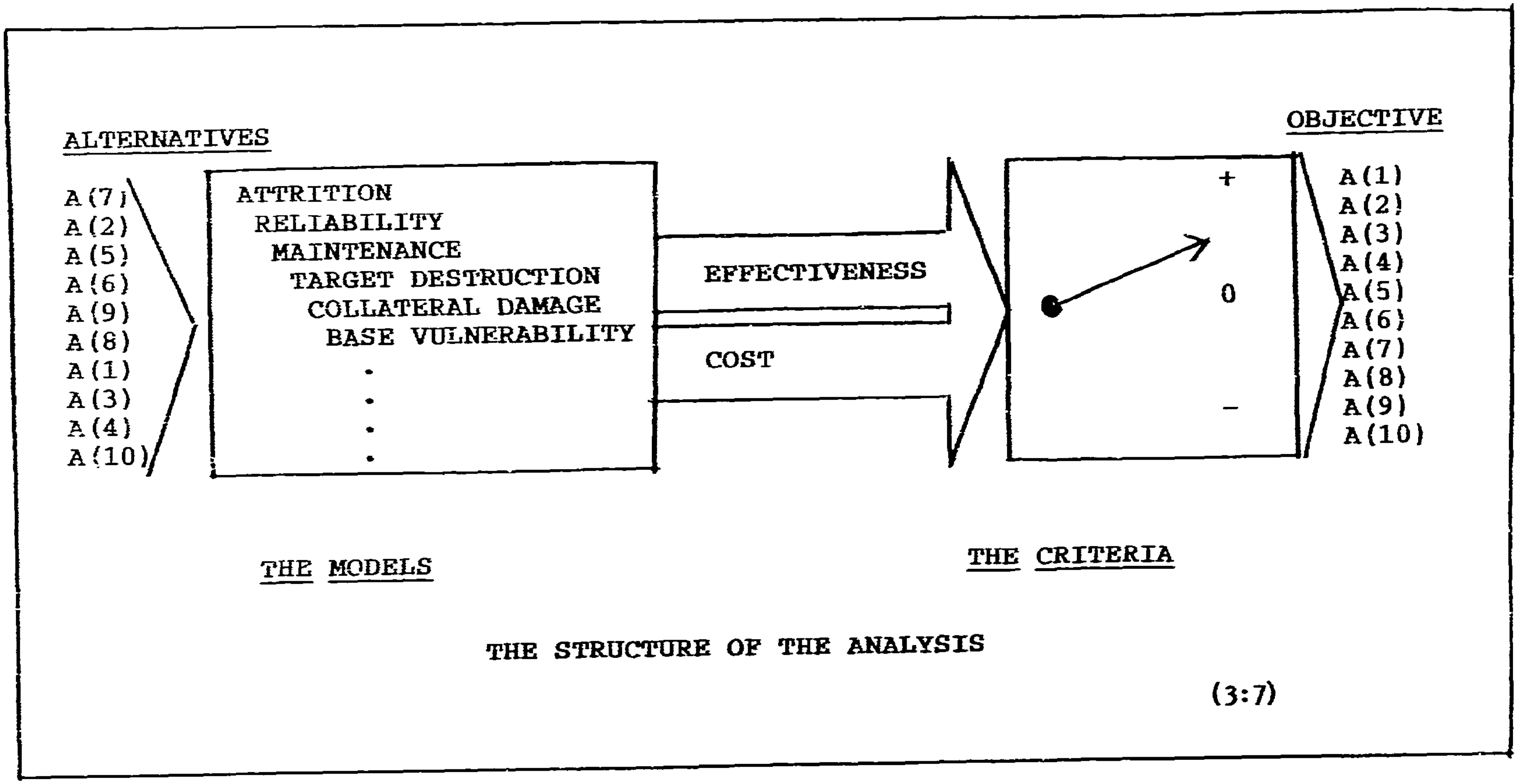


Fig. 1. General Cost Effectiveness Model

comparison of individual aircraft alternatives. Approaches that involve technology and aircraft mixes were not evaluated.

The Costs

The costs of the different alternatives were obtained from accepted Air Force publications, such as Air Force Regulation 173-13 (Cost Analysis: US Air Force Cost and Planning Factors) and the cost library of the Aeronautical Systems Division of Air Force Systems Command. The costs examined for the thesis included all facets of a system's life cycle.

The Criterion

The criterion that was used to evaluate the different alternatives were the total life cycle costs associated with the different systems, given a specific effectiveness level. This thesis evaluated three aircraft systems with regards to close air support mission requirements. In addition different levels of aircraft quantities were considered. Different aircraft quantities were examined, because the influence of R&D, O&M, and Production costs often differ over a range of aircraft numbers.

The Model

The crux of this thesis involved the development of a mathematical approach which incorporated mission effectiveness, readiness, and life cycle cost. The model that was developed in this thesis demonstrated a quantitative approach to the problem of comparing systems which incorporate high technology versus ones which rely on numbers.

Justification of Techniques

Aircraft Effectiveness. There have been many methods devised to either objectively or subjectively analyze the effectiveness of aircraft systems. Historically effectiveness was evaluated by simply examining the positive and negative characteristics of a system. In more recent times it has become increasingly difficult to measure effectiveness because of advanced technology and system complexity. In modern systems the sheer numbers and complexity of sub-systems make it physically impossible to evaluate all the characteristics without some type of advanced data processing.

A systematic approach to evaluate effectiveness of systems has been developed by the management science (operations research) professional discipline and is known as Multi-Attribute Value (MAV) analysis. This approach uses a mathematical algorithm which evaluates each

characteristic, or attribute as it is usually referred to, from the point of view of its value. Value refers to the attribute's contribution to the system's ability to meet a specified mission requirement. The values or attribute weights are assigned within the algorithm by an individual or set of individuals known as decision makers. The decision maker for this thesis was required to be an expert exceptionally versed in the mission area.

The strength of the MAV analysis is that it allows the researcher to compare very complex systems by breaking them down into manageable sub-elements, and to quantitatively evaluate the sub-elements. Ultimately, the MAV approach provides a logical and decomposable measure of a system's effectiveness.

The topic area of system effectiveness among close air support aircraft, using MAV theory, has been researched by Maj David P. Yonika (23) for a Masters thesis in 1985. The results of the research conducted by Maj Yonika were used as a major input to the effectiveness calculations used in this thesis. Due to different assumptions and research objectives some additional attributes were added to his original work.

Readiness. One of the foremost areas of concern within the Department of Defense is the readiness of its forces. For the purposes of this thesis, system readiness will be synonymous with the Fully Mission Capable (FMC) rate.

> Fully mission capable rate is the percent of possessed time that a system is capable of performing all of its assigned peacetime and wartime missions. (2:A2-2)

In this thesis the percent of aircraft that were fully mission capable was used in the calculations.

The United States Air Force uses many different methods to measure the actual operational time and total time possible for a weapon system; however, the one that will be used in this thesis will be data from the Weapon System Management Information System (WSMIS) database. WSMIS is a database maintained by the Air Force Logistic Command (AFLC). The data is generated by the commands which operate and support the different weapon systems.

Life Cycle Costs. The basic elements of a weapon system's life cycle costs are research and development, production, operation and maintenance, and disposal costs. The combination of all these costs compose the total systems life cycle cost. In order to adequately compare systems all of these costs must be addressed. The United States Air Force has developed a cost analysis regulation that;

> ...contains official U.S. Air Force cost and planning factors that can be used to estimate resource requirements and costs associated with Air Force force structures, missions, and activities. In particular, the regulation is primarily concerned with operating and support (O&S) cost estimates for Air Force aircraft. (6:i)

This thesis used the data available in AFR 173-13 in order to calculate the O&S costs associated with the different systems to be evaluated. The R&D and production costs were obtained from historical Air Force cost archives. Emphasis was placed on cost comparability. For the purpose of this thesis the disposal costs associated with the weapon systems were ignored. This was a somewhat reasonable assumption, because the dollar value associated with disposal is usually minimal as compared to the other costs.

Specific Methodology

An aircraft effectiveness calculation methodology was developed by Yonika using a Multi-Attribute Value (MAV) function. The MAV function is calculated using a computer program. The program is user friendly and provides a sensitivity analysis on the data. To demonstrate the computer program, Yonika evaluated close air support aircraft using a set of nine attributes. This thesis employed the computer MAV program and utilized the same Decision Maker (DM) used by Yonika. Due to the assumptions and approach taken in this research, the actual attributes used were examined and augmented as needed.

Attributes. the first step in evaluating the cost effectiveness of close air support aircraft was to

determine the mission objective that was being sought. This mission objective is the top element of a hierarchy of objectives. The sub-objectives were assumed to be independent of each other. Each individual sub-objective lead to the determination of a corresponding system attribute. The specific goal of the hierarchy was to achieve a logical stepwise breakdown of the mission objectives to the point where specific attributes, necessary to attain the objectives, could be obtained. The way the hierarchy works is that the introduction of the attribute performance levels and sub-objective values enables the ranking of alternatives with regards to the main mission objective (18:34-48).

Yonika developed a hierarchy for the close air support mission. This hierarchy is shown in Figure 2. Because of the different assumptions and specific scope of Yonika's research as compared to this research effort, possible additions to the sub-objectives and attribute set were explored. In light of current and historical CAS mission requirements, the Decision Maker (DM) was requested to evaluate the 9 attributes (Table I.) and recommend possible additions. Possible additions included aircraft armaments as an example.

Table I

Close Air Support Attributes Considered by Yonika

1. Sustained Turn Rate	6. In-route sustained speed
2. Maximum Instant	7. Maximum Speed
3. Take-off distance	8. Total Loitering Time
4. Landing distance	9. Combat Radius
5. Thrust-to-weight ratio	

(29)

There were many procedural requirements that must be followed to insure that the attributes used are valid with the MAV approach.

> It is important in any decision problem that the set of attributes be complete, so that it covers all the important aspects of the problem; operational, so the it can be meaningfully used in the analysis; decomposable, so that the aspects of the evaluation process can be simplified by breaking it down into parts; nonredundant, so that double counting of impacts can be avoided; and minimal, so that the problem dimension is kept as small as possible. (18:50)

Considerations of the above requirements have been observed and are discussed at length in Maj Yonika's thesis. To save time and to avoid lengthy rework of the effectiveness portion of this thesis, the research done by Yonika on the MAV computer program, the Pairwise Preferential Independance (PPI) existence among attributes, and the additive relationship of the value functions was considered sufficient for this thesis.

After the attributes were determined by the DM, he was instructed to rank order the different attributes with

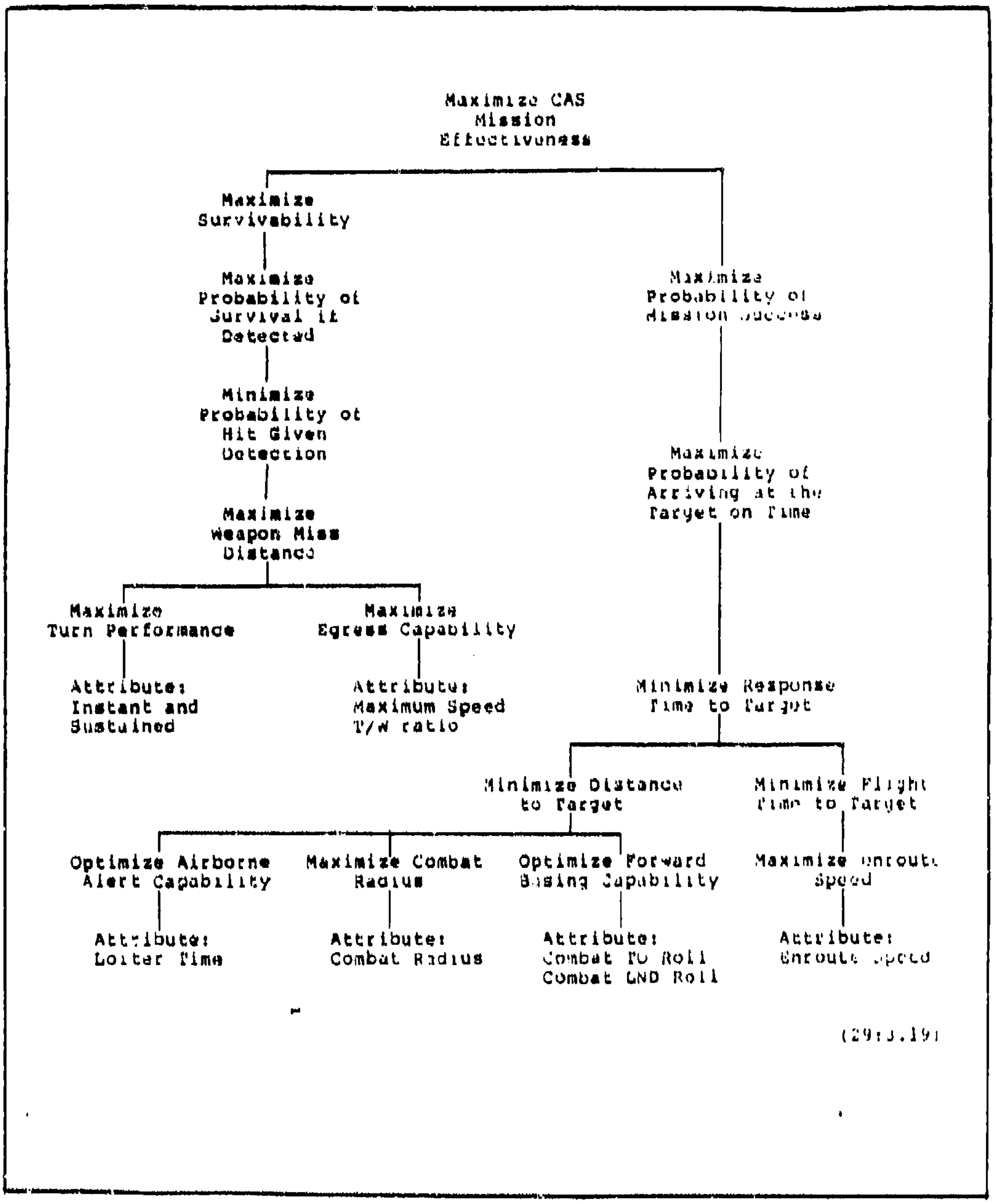


Fig. 2. Example of Close Air Support Hierarcny

regards to their importance to the close air support mission. This rank ordering of the attributes concluded the first phase of this thesis.

<u>Determine and Evaluate Respective Aircraft</u>. Phase two of this thesis involved the determination and evaluation of the representative aircraft to be used for the comparison. Within the past few years aircraft technology has grown a great deal within the aerospace industry. Many attempts have been made to separate aircraft systems with regards to the amount of technological sophistication they employ. Three categories of this technological sophistication are often referred to as high, medium, and low complexity. Aircraft that are considered to fit these three categories respectively are the F-15, F-16, and A-10 aircraft.

For this thesis the perceived categories of high, medium, and low complexity represented the ideal of system quality. The research assumption that is connected with this consideration is that the lower the "quality" of the aircraft the greater the numbers of aircraft required to effectively compensate for the lower technology.

The next step in the thesis process involved the collection of the phase 1 attribute values for the three aircraft being evaluated. Because of the general structure of this thesis, the three aircraft were used only to demonstrate the value of this cost-effectiveness approach over a representative range. For purposes of follow on

work, any number of aircraft can be used and evaluated using these techniques.

Multi-Attribute Value Function. The MAV function was used to determine the amount of each aircraft it would take to have a comparable effectiveness. The first stage of the MAV function analysis was to find and assign an expert Decision Maker (DM) from the mission area. For this thesis the DM was chosen because of his expertise and previous contribution as a DM to Major David Yonika's close air support study.

Individual Attribute Value Curves. The individual attributes determined in the first step of the research were broken down into individual value function curves. These value function curves showed quantitatively what the marginal value was for additional attribute performance. The purpose of these curves was to display each attribute, and its value over a predetermined range. These curves are particularly useful when the marginal value of additional performance is not linear. Because of the non-linearity of many real world situations, the use of these curves allow for a more realistic measurement.

The first step in developing the different value functions required that the individual attribute performance ranges be determined. This was accomplished by

reviewing the ranges of the aircraft which were to be evaluated. These ranges were then plotted over a normalized value range, with the lowest value being normalized at 0 and the maximum value being normalized at 1.00 .

To determine the actual value function curves the Decision Maker was asked to evaluate the individual attribute functions using a midvalue splitting technique. Because of the non-linearity of additional attribute performance, a midvalue splitting technique was used to build each value function curve. This technique divides the normalized values into individual points by halving the difference between the lower and higher attribute performance. The splitting or halving of the value function is accomplished by determining the point where the upper interval and lower interval are "differentially value equivalent" (18:120). That is to say, the point were the change from the lower value to this point is equal to the change from that point to the higher value. This splitting process was accomplished three times on each aircraft until value points are obtained for the 0, .25, .50, .75, 1.0 normalized levels. A sample attribute curve is shown in Figure 3. This process was continued for each attribute until all value function curves were developed.

The actual value function curves are DM dependant. The shape of the curves will be different from one DM to another, depending on their experience and biases.

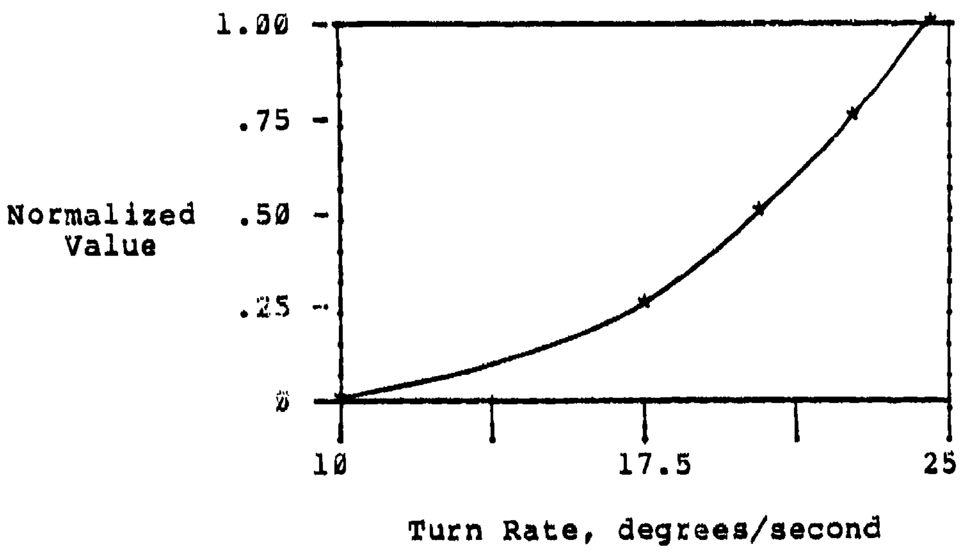


Fig. 3. Example Attribute Value Curve

Attribute Weights. The next step in the process was to develop the attribute weights. For this portion of the analysis the attributes needed to be ranked as to their importance. This ranking was performed in the first phase of the thesis process. The actual weighting process is as follows:

> ... the DM is asked to provide levels of attributes that would make the two alternatives equivalent or indifferent. The first [attribute] is tested with the second, the second with the third and so on. The DM is first given an alternative with all attributes at the lowest level except one, the 'i'th attribute. The level of the 'i'th attribute is set at a convenient level, the .5 value level, for example. The DM is then presented with a second alternative, on with all the alternatives (including the 'i'th) set at their lowest levels. The DM is asked to provide the level of the 'i+1' attribute that will make both alternatives equivalent. In this manner n-1 simultaneous equations are determined, this combined with the stipulation that all of the weights sum to one, the weignts can be calculated. (29:2.22)

Equalization Calculations. The major separation from traditional MAV function analysis occurs at this point in the research. The effectiveness values that were developed using the above mentioned techniques were only ordinal in nature. In order for the different aircraft to be compared it was necessary to evaluate them in a ratio fashion. The method that was employed to do this transformation involved the manipulation of the aircraft attributes values.

Step one, the aircraft attributes from phase one were evaluated to determine which of them were influenced by changes in aircraft numbers. Step two, the curves of those attributes were manipulated until all three aircraft had the same effectiveness value. The aircraft ratios obtained from this evaluation were equivalent to the amount of additional aircraft numbers needed to make the effectiveness values equal. By following this procedure and having the effectiveness values equal, the researcher can infer that the effectiveness of each aircraft set is equal or indifferent in a comparison. For example, if 1.5 of aircraft #1 are required to increase its effectiveness value so that it is equal to aircraft #2, the ratio of aircraft one to two would be 1.5 to 1.

Readiness Values. Information from the WSMIS data bank was obtained on the three weapon systems' Fully Mission Capable (FMC) rates. This information was in the form of the percentage of time the aircraft was fully mission capable for missions during the last 2 years. Care was taken to avoid the incorporation of other than "steady state" availability information. For purposes of this thesis the term steady state refers to the relative equilibrium of the data. The availability percentage was the normal expected Average FMC percentage, not positive or negative extremes.

The availability data was incorporated into the effectiveness ratio by dividing the respective effectiveness ratio number by the percent availability number. This incorporation of availability data adjusted the effectiveness ratios to include aircraft readiness. These adjusted effectiveness ratios represent the number of each aircraft necessary to meet the same effectiveness goal. The lower the availability percentage , the greater the number of aircraft required. For example, an aircraft system with an availability percentage of .90 and an individual effectiveness of one, would require that 1.11 aircraft be available on the flight line.

The adjusted effectiveness ratios obtained from these calculations were considered the Equilization "E" ratio. The "E" ratio was used later in the research to develop the equivalent cost-effectiveness curves.

__Life Cycle Costs Associated w/Aircraft__. The next step in the thesis was to obtain and evaluate the Life Cycle Costs (LCC) for the F-15, F-16, and A-10 aircraft. This included the determination of the research & development, production, and operational costs for each of the aircraft. The LCC data for all three aircraft systems were obtained from AFR 173-13, the BDM Corporations study on Quantity Versus Quality (3), and the ASD cost library. Emphasis was placed on confirmation that the information from these libraries and references contain equivalent and comparable cost information. A series of aircraft cost curves were constructed using the LCC data. The cost curves were built by first incorporating the R&D costs. These costs included the development of the first production model aircraft, as well as R&D costs associated with other more advanced aircraft models.

The total R&D costs were provided as a baseline to which the other two costs were added. The Operation and Support and production costs were then introduced. The curves were arranged so that total costs were on the ordinate and the numbers of aircraft were on the abscissa. An example of the individual aircraft cost curve is shown in Figure 4. Note that the O&S, and Production costs are actually step functions. However, over the large range the curves appear linear.

Cost-Effectiveness Model Calculations. The values that were obtained from the previous procedures were combined in this stage of the research. The internal manipulations within the MAV function provided the basic effectiveness ratio of F-15:F-16:A-10. This ratio was then combined with the steady-state availability information obtained from the WSMIS database. This procedure incorporated the readiness information with the basic effectiveness ratio. As mentioned

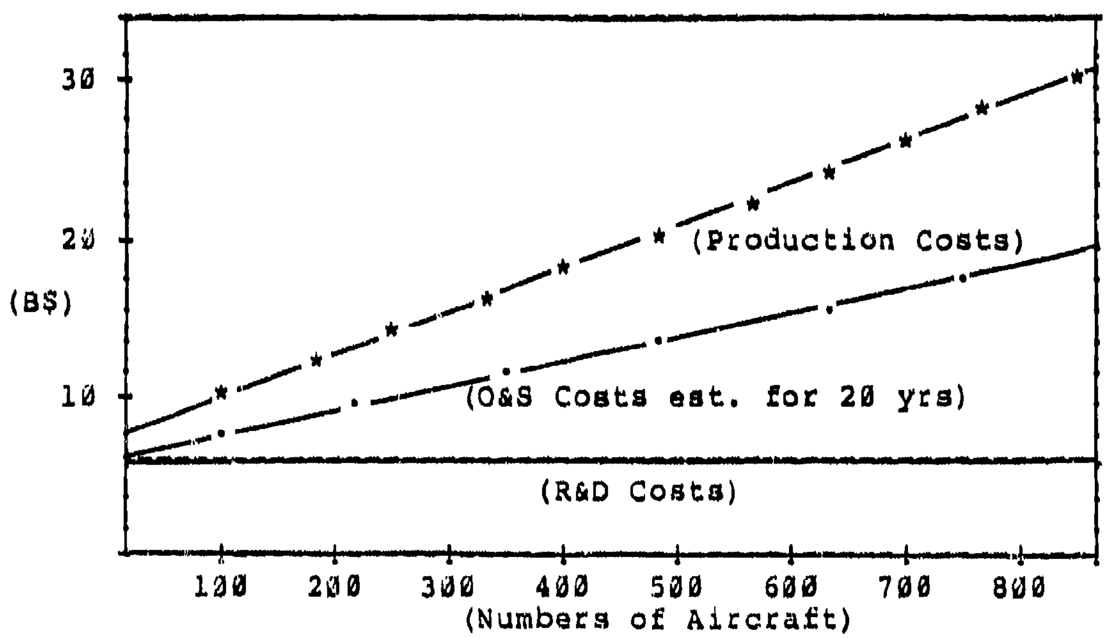


Fig. 4. Example Aircraft Cost Curve

earlier, this new ratio was considered the Equalization "E" ratio. The idea behind the E-factor is that it is an estimate of how many of each of the three aircraft are required to perform an equivalent mission.

The "E" factor provided a base from which the cost comparisons were developed. The development of the "E" ratio was, in essence the model portion of the Cost-Effectiveness analysis.

In order to evaluate the comparative cost per aircraft system the LCC information and "E" ratio were introduced into the model. The cost per aircraft information was adjusted to the "E" factor ratio. This incorporation of LCC to the data obtained from the mission effectiveness and reliability calculations provided a comparison of the three systems over a range of different aircraft numbers.

The final step in the thesis was to compare the different total aircraft costs over various quantities. The graphical display of this information provided a more accurate cost-effectiveness association between the different aircraft systems.

IV. Calculations and Analysis

This chapter presents the data, calculations, and analysis found and developed in conjunction with this thesis. The presentation of the data and calculations will follow the methodology set forth in chapter 3.

Determination of Attributes

As mentioned in chapter 3, the actual attributes used for the study are determined through the development of a Close Air Support (CAS) mission hierarchy. The top element of that hierarchy is the mission objective. In this case the mission objective was to maximize Close Air Support (CAS) effectiveness.

The foundation for the hierarchy used in this thesis has been shown in Figure 2. Additional research into the subject of the CAS mission prompted the inclusion of aircraft armaments into the hierarchy. This required that one new sub-element be added to the basic hierarchy developed by Yonika. The added sub-element was to 'maximize the probability of a kill'. This sub-element is an additional lower tier of 'maximizing the probability of mission success'. The rational behind this inclusion is that CAS mission success is more than just arriving at the target on time. It has to include the probability that the

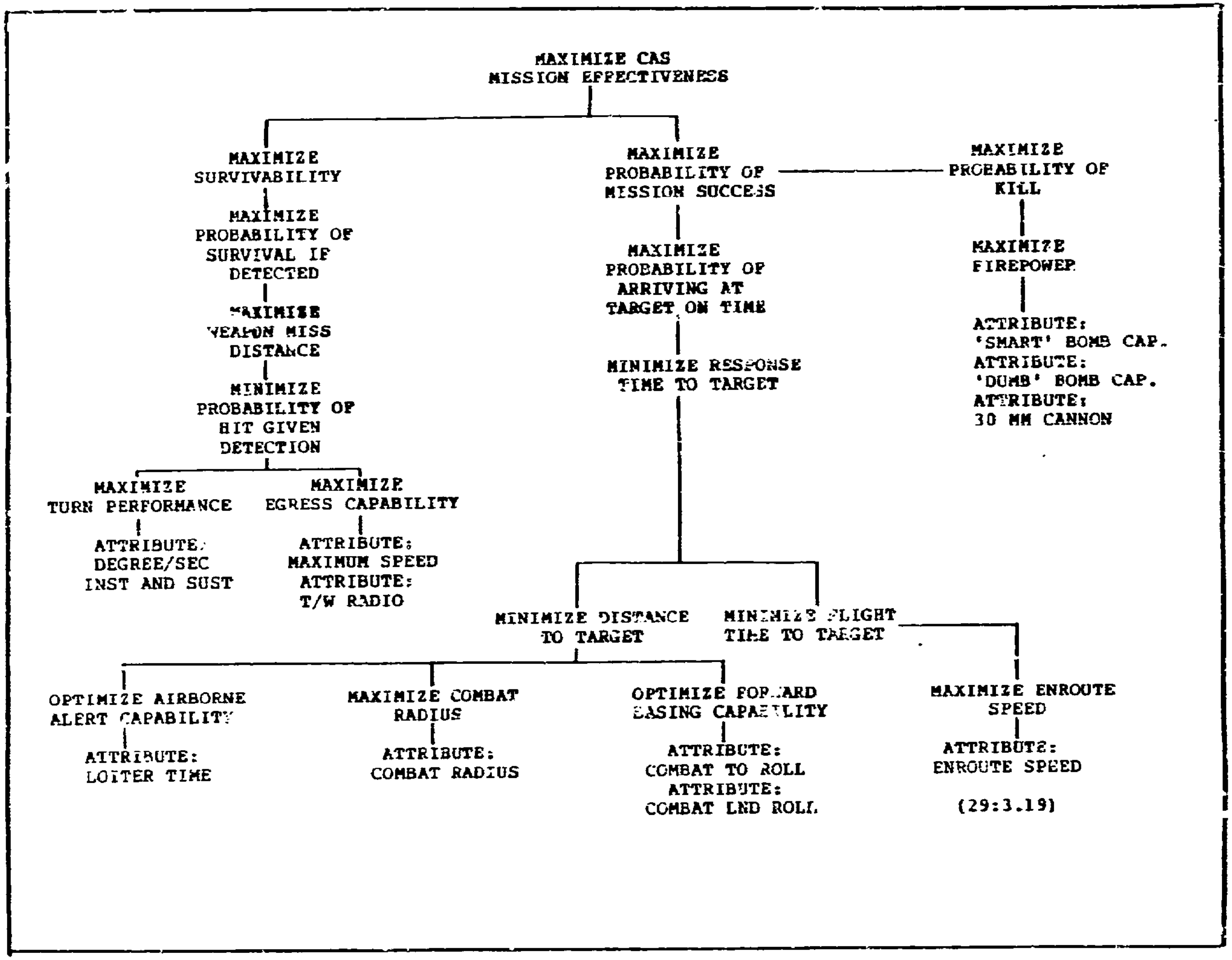


Fig. 5. Augmented Close Air Support Hierarchy

enemy can be defeated or contained. The sub-element 'probability of kill' is further defined by its lower tier element 'maximize firepower'. Maximizing firepower introduces aircraft armaments into the hierarchy as new attributes. The types of armaments have been broken into 3 types: smart bombs, dumb bombs, and projectile cannons. The new CAS hierarchy is illustrated in Figure 5.

The enhanced CAS hierarchy contains 12 individual aircraft attributes that were used in the Multi-attribute Value analysis. The new set of aircraft attributes are shown in Table II.

Table II

Close Air Support Attributes Considered for Analysis

1. Sustained Turn Rate*	8. Total loitering time*
2. Maximum Instant Turn Rate*	9. Combat radius*
3. Take-off distance*	10. "Smart" bomb capacity
4. Landing distance*	11. "Dumb" bomb capacity
5. Thrust-to-weight ratio*	12. Projectile Cannon 30mm
6. In-route sustained speed*	
7. Maximum speed*	

* Attributes obtained from Maj Yonika's Thesis (29).

Rank Ordering of Attributes

In order to assign individual weights to the attributes, it was necessary to rank them in order of their importance. To do this the Decision Maker (DM) was given the attributes as shown in Table II and asked to prioritize

them with 1 being the most important, 2 the next in line and so on. In addition to ranking the individual attributes, the DM was asked which of the attributes would be effected by increased aircraft numbers. The attribute ranking and the analysis for the impact of increased numbers, as provided by the DM, is displayed in Table III.

Table III

Ranked Close Air Support Attributes Considered for Analysis

ATTRIBUTES	MEASURE	IMPACTED BY NUMBERS
1. Sustained Turn Rate	Deg/Sec	NO
2. Maximum Instantanious Turn Rate	Deg/Sec	NO
3. Projectile Cannon (30mm)	numbers	YES
4. "Smart" bomb capacity	numbers	YES
5. Thrust-to-weight ratio	T/W	NO
6. Maximum speed	Mach	NO
7. Total Loitering time	Hr	YES
8. "Dumb" bomb capacity	numbers	YES
9. Combat Radius	Nm	NO
10. In-route sustained speed	Nm/hr	NO
11. Combat Take-off distance (roll)	Ft	NO
12. Combat Landing distance (roll)	Ft	NO

Determination of Aircraft Performance Levels

In order to evaluate the different aircraft with regard to their effectiveness it was necessary to first determine the individual aircraft performance levels. The performance parameters for each of the three aircraft were restricted to a typical CAS mission scenario. Despite the fact that it is difficult to come up with a "typical" CAS

performance set for each aircraft, the literature and informed sources suggest that the values displayed in Table IV are reasonable. (15; 11:1) The four attributes that were identified by the DM as being impacted by numbers are shown in brackets.

Table IV

Individual Aircraft Attributes

Acry.	Aircraft		
	A-10	F-16	F-15
STR	12	14.8	13.5
MITR	18	22	23.5
PC	[1]	[0]	[0]
SB	[4]	[6]	[8]
T/W	.42	1.1	.95
MS	.65	1.1	1.1
TLT	[1.7]	[.5]	[.5]
DB	[0]	[1]	[2]
CR	250	500	350
ISS	300	500	540
TOD	1450	1500	2700
LD	1300	1500	4500

From the attribute levels in Table IV a set of ranges for each of the 12 attributes was obtained. The attributes and their respective ranges are listed in Table V. Note that the 4 attributes previously identified as being effected by increased numbers have ranges in excess of than any of the individual performance values found in Table IV. The larger range values were introduced to allow for multiple aircraft calculations in the equalization 'E'

equation. The 'E' calculations will be presented later in this chapter.

Development of Attribute Value Curves

The next step of the analysis required that individual value curves be developed for each of the attributes determined from the CAS hierarchy. Each value curve was normalized over a range of 0 to 1 and included the attribute ranges provided in Table V.

Table V

Attribute Ranges

Attribute	Acry.	Range
Sustained Turn Rate	(STR)	10-25 degs/sec
Max. Instant Turn Rate	(MITR)	16-32 degs/sec
Projectile Cannon (30mm)	(PC)	0-3 Cannons
"Smart" Bomb Capacity	(SB)	3-12 Bombs
Thrust-to-Weight Ratio	(T/W)	.40-1.5 T/W
Maximum Speed	(MS)	.65-1.5 Mach
Total Loitering Time	(TLT)	.25-4.8 Hours
"Dumb" Bomb Capacity	(DB)	0-3 Bombs
Combat Radius	(CR)	200-500 Nm
In-Route Sustained Speed	(ISS)	300-550 Nm/Hr
Combat Take-off Distance	(TOD)	1000-4000 Ft
Combat Landing Distance	(LD)	1000-4600 Ft

Table V was developed using the mid-value splitting technique explained in chapter 3. The responses provided by the DM to the mid-value splitting questions and the subsequent curves are displayed in Appendix A.

Attribute Weights

The weights of the individual attributes were obtained from the Multi-attribute Value (MAV) computer program provided by Yonika. The program was designed to provide a series of comparative questions about the attributes to the DM and to collect his respective answers. The questions were organized in a sequence determined by the priority of the individual attributes. From the DM's responses a set of simultanious equations were constructed and solved. The solutions to the simultanious equations determined the weighting of the different attributes. The comparative questions and DM responses are displayed in Appendix B. The weights obtained from the computer program for the different attributes are shown in Table VI.

Table VI

Attribute Weights

Attribute	Acry.	Weight
Sustained Turn Rate	(STR)	.259
Max. Instantanious Turn Rate	(MITR)	.240
Projectile Cannon (30mm)	(PC)	.223
"Smart" Bomb Capacity	(SB)	.223
Thrust-to-Weight Ratio	(T/W)	.024
Maximum Speed	(MS)	.012
Total Loitering Time	(TLT)	.009
"Dumb" Bomb Capacity	(DB)	.002
Combat Radius	(CR)	.002
In-Route Sustained Speed	(ISS)	.002
Combat Take-off Distance	(TOD)	.002
Combat Landing Distance	(LD)	.002
		1.000

Equalization Calculation

The first step toward equalization was to process the attributes values for the three individual aircraft using the weights and value curves developed by the DM and the MAV computer program. In addition, the attribute values for two A-10s and two F-16s were also included. Multiple aircraft are represented, in this thesis, by identifying the attributes effected by increased numbers and increasing their values by a multiplier. All the other attribute values from the single aircraft sets are not affected. In this case the multiplier is 2, since we want to determine the effectiveness values for 2 aircraft. The attribute values for two A-10 and two F-16 aircraft are shown in Table VII as an example.

Table VII

Multiple Aircraft Attributes

	Aircraft	
Acry.	A-10 (2)	F-16 (2)
STR	12	14.8
MITR	18	22
PC	[2]	[0]
SB	[8]	[12]
T/W	.42	1.1
MS	.65	1.1
TLT	[3.5]	[1.0]
DB	[0]	[2]
CR	250	500
ISS	300	500
TOD	1450	1500
LD	1300	1500

Note that in Table VII the four attributes that were flagged as being impacted by increased numbers are now twice as large as those found in Table IV for the individual aircraft. The five different aircraft attribute sets were run using the MAV computer program. The computer program calculated and displayed the rankings and MAV values for each of the five attribute sets. These values and rankings are shown in Table VIII.

Table VIII

Aircraft Ranking

Ranking	Alternative	Value
1	F-16 (2)	.386
2	A-10 (2)	.309
3	F-15	.285
4	F-16	.236
5	A-10	.133

Table VIII shows that amongst the three single aircraft the F-15 is ranked the highest. However, when two F-16s or two A-10s are introduced, they become more effective. The next step of the equalization process was to find the exact numbers of F-16s and A-10s that would make them equal in ranking to one F-15 aircraft. This was accomplished by iteratively calculating the values of F-16 and A-10 aircraft from partial or fractional aircraft numbers, such as 1.5, until the value .285 (F-15 value) was achieved.

This process took approximately 6 iterations to find the appropriate values. The number of aircraft, attribute, and ranking values that were finally determined are shown in Table IX (15; 11:1).

Table IX shows that the ratio of 1 F-15 to 1.86 A-10s or 1.33 F-16s is of equal value to the Decision Maker (DM). In effect the ratio depicts the amount of each aircraft type necessary to be equally effective in this study of the CAS mission area.

Table IX

Equalization Calculation

Attribute Aircraft #	A-10 (1)	F-16 (1)	F-15 (1)	A-10 (1.86)	F-16 (1.33)
STR	12	14.8	13.5	12	14.8
MITR	18	22	23.5	18	22
PC	1	0	0	1.86	0
SB	4	6	8	7.44	7.98
T/W	.42	1.1	.95	.42	1.1
MS	.65	1.1	.95	.65	1.1
TLT	1.7	.5	.5	3.16	.67
DB	0	1	2	0	1.33
CR	250	500	350	250	500
ISS	300	500	540	300	500
TOD	1450	1500	2700	1450	1500
LD	1300	1500	4500	1300	1500
Rank Values	.132	.235	.285	.285	.285

In order to identify a confidence interval for this study, a form of sensitivity analysis was run. In addition to the questions asked of the DM mentioned in appendix B,

the DM was asked to provide a plus and minus range for each of his answers. An analysis identical to the one run to determine the equalization ratios was run using the 'minus' and another using the 'plus' values. The intent of this was to provide a sensitivity range for the equalization ratio values. The results of the two computer runs were an effectiveness ratio of F-15:A-10:F-16 of 1 : 1.74 : 1.37 for the minus end of the scale, and 1 : 2.01 : 1.26 for the plus end of the scale using the F-15 value as the baseline. The significance of this analysis is that it provides a range for the numbers provided by this thesis. The variation in the effectiveness ratio for the A-10 was determined to be plus or minus 8% and for the F-16 plus or minus 5%.

Readiness Calculations

The readiness values used for this research were obtained from the Weapon System Management Information System (WSMIS) operated and maintained by the Air Force Logistics Command. As a surrogate for readiness, Fully Mission Capability (FMC) rates for the three aircraft were used. The WSMIS data bank provided the FMC rates for the three aircraft by month for the last two years. The FMC rates by month were then averaged for each aircraft. The monthly FMC values and the parameters used for the WSMIS search are displayed in appendix C.

The average FMC rates for the three aircraft are as follows; F-15 (70.39), F-16 (74.07), and A-10 (77.24). These numbers indicate the average percent of aircraft that were FMC over the last 2 years. These numbers are combined into the cost-effectiveness model by dividing the equalization ratio by the average FMC percent. In essence if the aircraft is not available 100% of the time, more aircraft must be provided to maintain the same effectiveness. As an example, consider an aircraft which is FMC fifty percent of the time. If an effectiveness of 1 plane were required, 1/.50 or 2 planes would be necessary. This provides an adjusted equalization ratio which takes into account effectiveness and availability considerations. The adjusted equalization ratios for the three CAS aircraft are; F-15 (1.42), F-16 (1.80), and A-10 (2.41). When the values are normalized with the F-15 being 1.00 the other aircraft become 1.27 for the F-16 and 1.69 for the A-10.

The significance of these numbers is that they show how many of each aircraft are required to provide equal effectiveness in the CAS mission area. For example, the numbers suggest that it would require 169 A-10s or 127 F-16s to provide the same CAS effectiveness as 100 F-15s.

Aircraft Cost Curves

The next phase of the thesis was to determine the cost curves for the individual aircraft. As mentioned in the methodology section, the costs associated with each aircraft were broken down into 3 separate cost areas. the first is Research and Development (R&D), the second is Operations and Maintenance (O&M), and finally the third is individual production costs.

The R&D costs for each of the three aircraft, as determined by a BDM Corporation study, are \$3.58 Billion for the F-15, \$1.15 Billion for the F-16 ,and \$.70 Billion for the A-10 aircraft (3:17). These values are in FY 81 dollars.

The O&M costs for each of the three aircraft were obtained from AFP 173-13, and are estimates based on a 24 Primary Aircraft Authorization (PAA) squadron and FY 81 dollars. The figures are broken out in Table X. The annual O&M costs for each of the three aircraft per 24 PAA are \$40.76 M for the F-15, \$32.50 M for the F-16 ,and \$24.82 M for the A-10 aircraft (3:21). For purposes of this thesis the average life of the individual aircraft was projected to be 20 years.

Table X

Annual O&S Cost Per 24 PAA Squadron
(Millions, FY 81 dollars)

Cost Element	F-15	F-16	A-10
1.0 UNIT MISSION PERSONNEL	8.52	7.54	6.74
2.0 UNIT LEVEL CONSUMPTION			
2.1 POL	9.56	6.07	4.49
2.2 AIRCRAFT MAIN MTLS	2.07	1.50	1.13
2.3 TRAINING ORDNANCE	0.10	2.30	2.20
3.0 DEPOT MAINTENANCE	7.29	6.83	2.61
4.0 SUSTAINED INVESTMENT			
4.1 REPLENISHMENT SPARES	4.79	2.44	2.97
4.2 REPLENISHMENT SPT EQPT	1.20	0.65	0.37
4.3 MODIFICATION KITS	2.48	1.17	0.89
5.0 INSTALLATION SUP SALARIES	1.38	1.09	0.77
6.0 INDIRECT PER SALARIES	1.20	1.05	0.90
8.0 ACQUISITION AND TRAINING	1.99	1.86	1.75
TOTAL	40.76	32.50	24.82

(3:21)

The production costs, in 1982 dollars, for each of the aircraft as provided in the 1982 Selected Acquisition Report (SAR) were $27.16 M for an F-15, $19.63 M for an F-16, and $6.80 M for an A-10 aircraft.

By combining the three aforementioned aircraft costs, and adjusting the values to FY 85 dollars, individual cost curves for the three aircraft were determined. The three cost curves are displayed in Figures 6 through 8.

Cost-Effectiveness Curve

The individual cost curves displayed in Figures 6, 7,and 8 were combined into one single cost-effectiveness

curve. The combination curve retained the same cost values on the ordinate, however, the numbers of aircraft on the abscissa are displayed using the adjusted equalization ratios determined earlier in this chapter. The results of this combination is displayed in Figure 9. The total cost lines, for the three aircraft, are shaded to reflect the confidence ranges associated with the effectiveness ratios.

In order to compare the three aircraft side by side using the equalization ratios, some of the partial aircraft numbers had to be rounded up to the nearest whole number. This rounding process did not significantly effect any of the cost-effectiveness curves and was ignored.

The significance of the final cost-effectiveness graph is that it allows the casual observer to compare the three aircraft with respect to cost and effectiveness. This type of graphical display allows the reader to compile a series of 'what ifs' at a glance. An example of a possible comparison would be the determination of how much it would cost to have the same effectiveness as 300 F-15s using F-16s or A-10s. This could be done by locating 300 F-15s on the abscissa and drawing a vertical line. The point on the ordinate were the vertical line crosses the A-10 or F-16 curve shows the cost associated with equal effectiveness.

Other helpful information that can be obtained from the curve is the numbers of personnel required to fly the different aircraft for given effectiveness levels.

Additional comparisons, evaluations, and comments are provided in chapter 5.

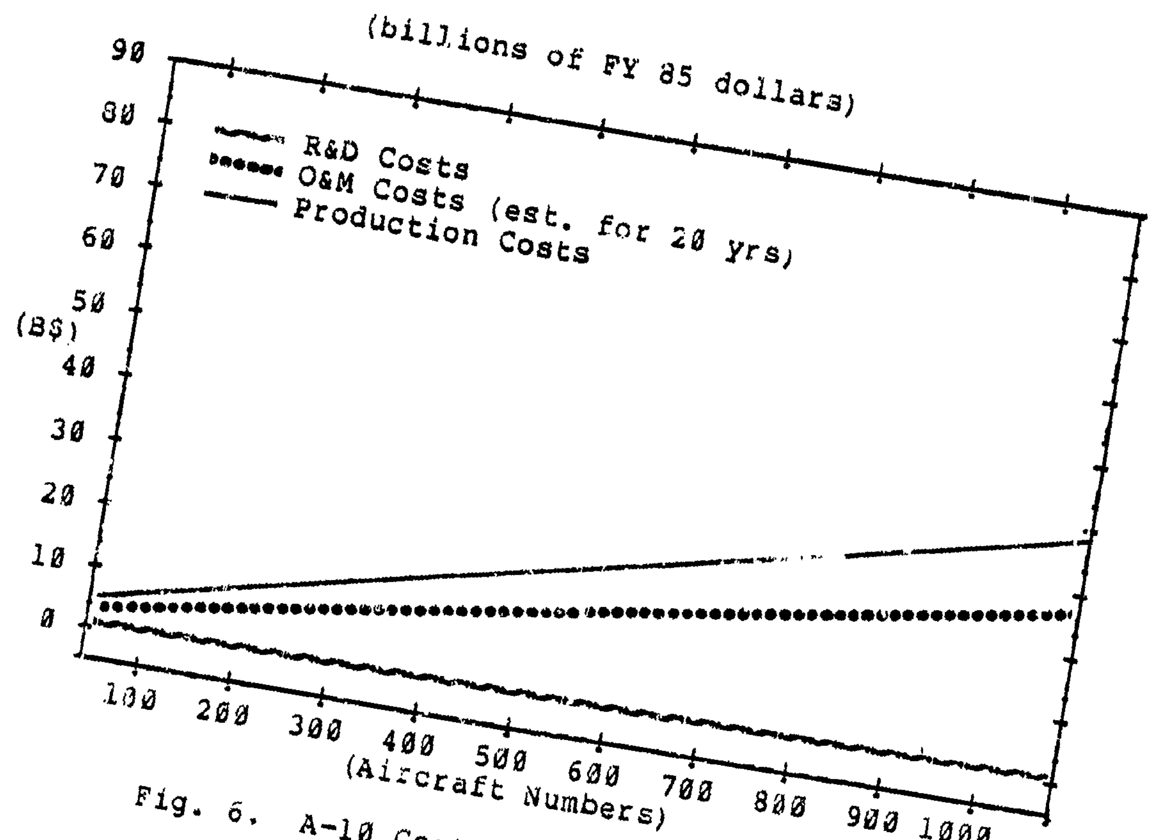


Fig. 6. A-10 Cost-Effectiveness Curve

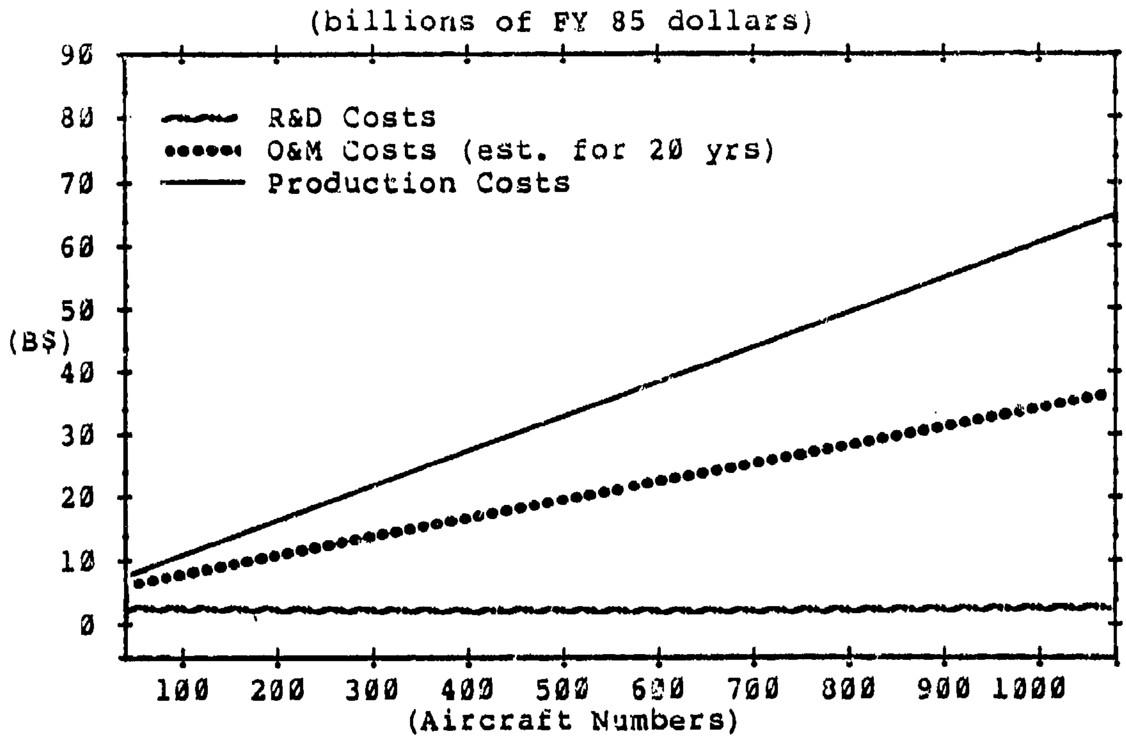


Fig. 7. F-16 Cost-Effectiveness Curve

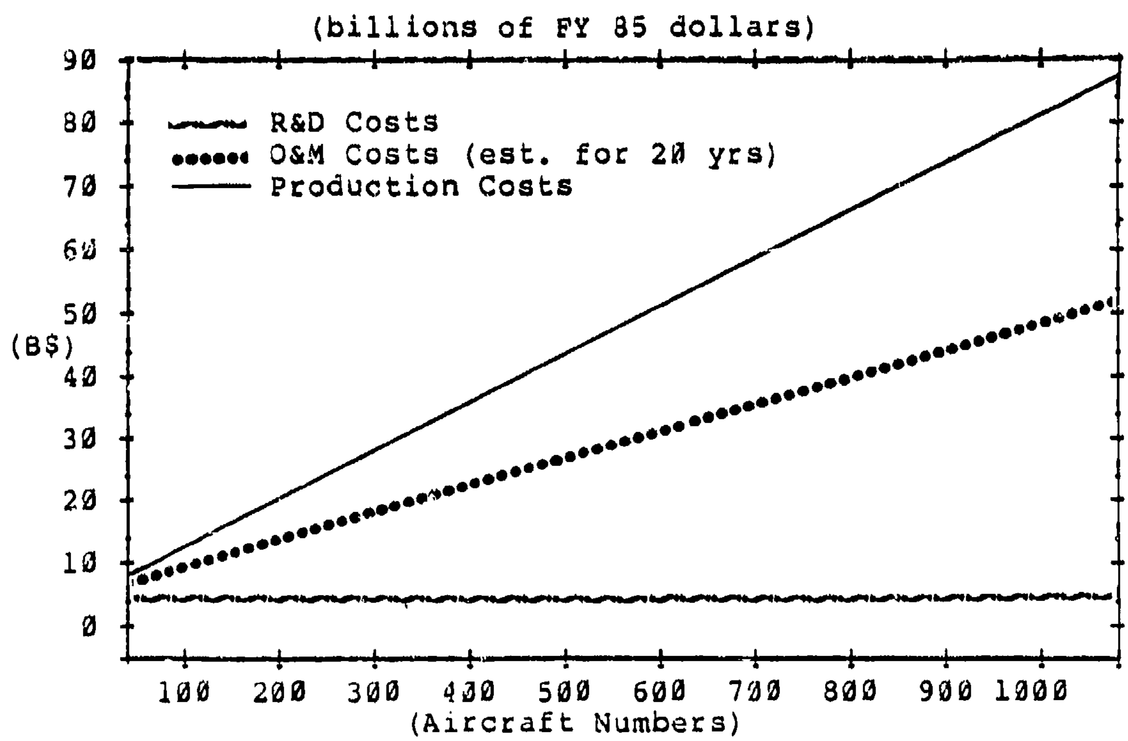


Fig. 8. F-15 Cost-Effectiveness Curve

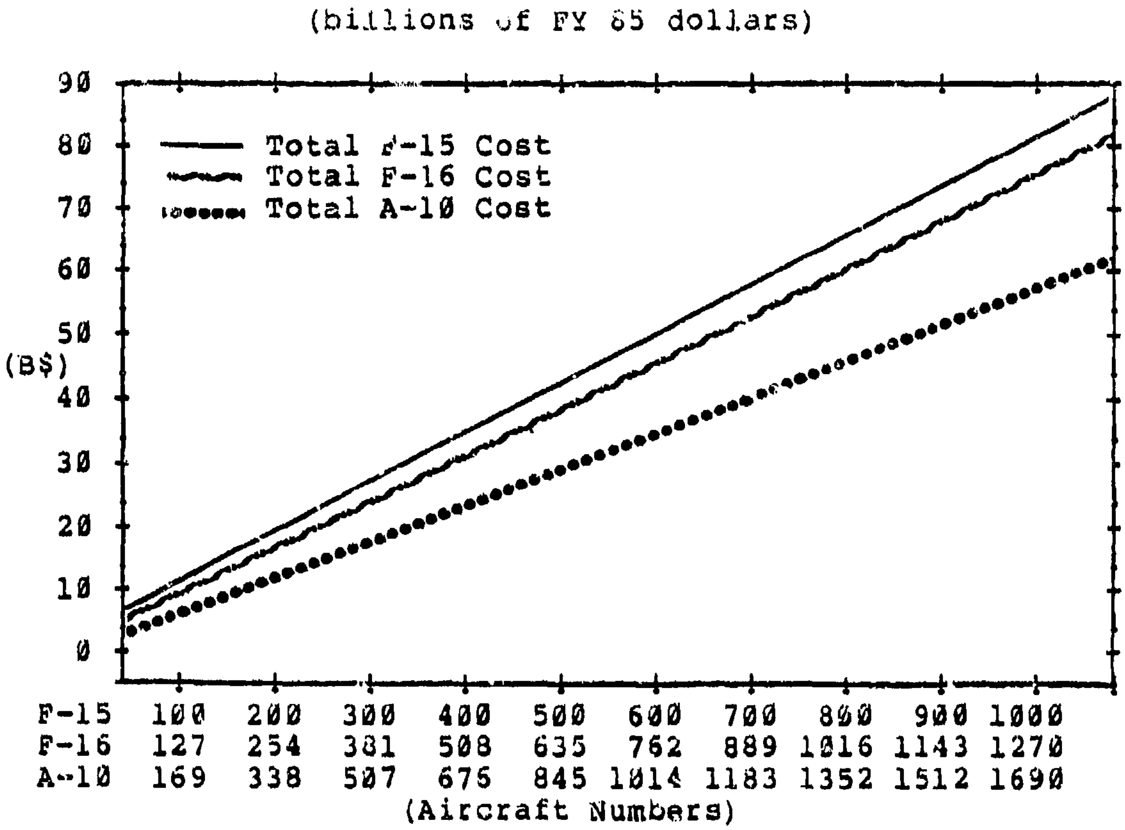


Fig. 9. Combined Cost-Effectiveness Curve

V. Summary and Conclusions

Summary of Research

The primary emphasis of this research effort has been to investigate the quantity versus quality issue and to design a cost-effectiveness model to aid in evaluating it. This model incorporates mission effectiveness, readiness, and life cycle costs. The research effort was hinged around a case study comparison of the F-15, F-16, and A-10 aircraft. These aircraft were chosen because they represented varying system complexities and were used as surrogates to high, medium, and low complexity respectively. The comparisons made in this thesis were intended to demonstrate the usefulness of using aircraft effectiveness, readiness and cost data in a mathematical cost-effectiveness model.

The methodology that was followed in this research involved combining multi-attribute value theory, aircraft readiness figures, and aircraft life cycle cost information. The result of this approach was a series of cost-effectiveness ratios, and a cost-effectiveness curve which incorporated the three close air support aircraft. The cost-effectiveness curve provided the costs, adjusted by both effectiveness and readiness values, associated with the three aircraft.

Conclusions of the Research Effort

The research results indicate that the approach used to develop a cost-effectiveness model does provide a quantitative way to evaluate the problem of quantity versus quality. The values presented in the combination cost-effectiveness curve (Figure 9) show that the incorporation of aircraft effectiveness and readiness does indeed alter the comparison between the three aircraft. Using 1100 F-15's as a baseline, the difference in terms of cost between the A-10 and the F-15 went from $49 Billion in the equal number comparison to only $25 Billion when the equalized ratios were used. The difference in terms of aircraft numbers went from an equal amount to 1000 for the F-15 and 1690 for the F-16. The new equalized figures should allow defense planners and managers to get a better overall picture of the differences between the aircraft. In this case the increased numbers of A-10s and F-16s required to equal the performance effectiveness of the F-15 did not alter the cost-effectiveness rankings. However, this may not always be the case. In the situation where the cost curves cross, the defense planner would have a different cost-effectiveness ranking depending on how many aircraft were evaluated.

The amount of information that was required for this model is considerable. As mentioned in Chapter 1, the approaches to date to the quantity versus quality problem

have only evaluated portions of the necessary information. The approach taken by this research required that a Decision Maker (DM) answer a series of questions. These questions inturn were used to produce a series of weights and value curves which ultimately determined the effectiveness ratios of each of the aircraft.

This approach has both advantages and disadvantages. One of the positive factors of this systematic approach, was that it helped to eliminate many individual biases often seen in the quantity versus quality controversy. Biases were lessened by breaking the problem into small sub-elements. The DM was asked to evaluate many smaller pieces of information rather than one large piece. This made it difficult for the DM to bias the study one way or another.

Another advantage of this method was that it allowed a large number of variables to be incorporated into the study. Without this type of approach it is very difficult, if not impossible, for an individual to process all the variables needed for the study. The amount of information that an individual can process is limited. It is commonly accepted that an average individual can only process around 7 pieces of information at a time. This would surely limit his ability to evaluate all of the variables in the quantity versus quality problem.

Some of the disadvantages of this approach are that the DM often feels that the information that he has provided is fed into a form of 'black box'. The DM therefore does not always feel comfortable with the final weights and values. This type of reaction may also be present with the defense planners and managers that are expected to use the information from the analysis. Many of the planners and managers may also object to the expert dependent nature of this approach. The effectiveness numbers are of course dependent on the experts answers and therefore influenced by his biases.

Another disadvantage of this method is that some of the information required to perform the comparisons is voluminous and not readily available through other programs or databases. This makes the collection of that data costly. If this method were to be attempted by a System Program Office (SPO) activity, the information required would have to be used for other purposes in order to make it cost effective. An example of an additional use of the data can be demonstrated with the attribute value curves. These curves could be used by the program manager to identify performance areas to provide Pre-planned Product Improvement (P3I) emphasis.

The key result of this research is that it presents a quantitative method to combine the many factors that need to be considered in the quantity versus quality issue.

This quantitative method provides a reproducible and systematic way to evaluate systems with different capabilities, readiness, and life cycle costs. The final aircraft cost-effectiveness curve allows the defense manager to compare the costs associated with equal effectiveness as well as other valuable information. The other information includes the determination of how many aircraft can be bought for a given price, and estimations of personnel requirements for equivalent weapon systems.

Recommendations

The methodology developed in this research was designed to show that this mathematical approach is possible, and provides valuable information needed for the comparison of weapon systems with different performance capabilities. The actual effectiveness calculations were developed from one expert's inputs, and are not particularly the best or most unbiased available. Because of this, the actual data points on the cost-effectiveness curves are valid for that expert only, and are for demonstration purposes. For an accurate effectiveness calculation, additional people in more diverse disciplines are needed to provide input.

Despite the limitations mentioned, the cost and readiness data provided in this analysis is accurate and reproducible. The methodology is sound and built on previously proven methods. The value, to the defense

decision maker, of the information provided in this thesis is still to be determined.

Suggestions for Further Research.

This study examined only the Close Air Support mission area, and involved the F-15, F-16, and A-10 aircraft. Other mission areas and weapon systems should be evaluated using this approach.

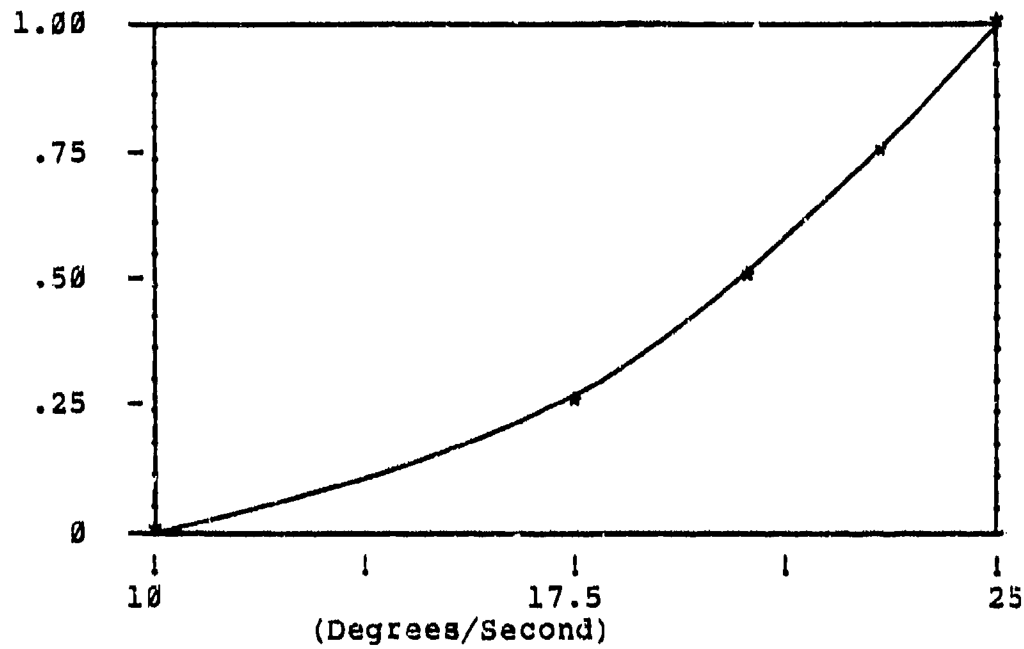
The same study should be rerun using more decision makers from more diverse disciplines. The information for readiness, and life cycle costs should be obtained from experts in those fields using more state of the art methods available today.

The results of this study and methodology should be presented to the Air Force community to determine how well accepted the data would be. A study should be designed to evaluate the strengths and weaknesses of this method over other conventional cost-effectiveness models.

Appendix A: Individual Attribute Value Curves

This appendix provides the questions, answers and resulting value curves obtained from the interview with Major Jack Shafer the DM.

Sustained Turn Rate (STR)

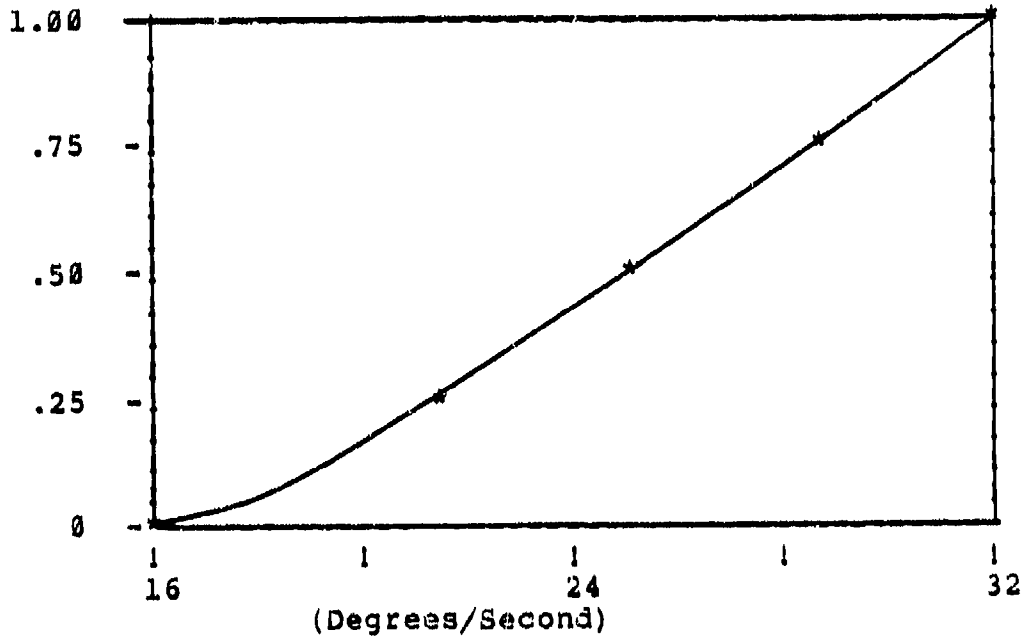


FOR (Sustained Turn Rate) AT WHAT POINT IS THE CHANGE FROM (10 deg/sec) TO THIS POINT EQUAL TO THE CHANGE FROM THAT POINT TO (25 deg/sec). THAT POINT IS (20 deg/sec).

FOR (Sustained Turn Rate) AT WHAT POINT IS THE CHANGE FROM (10 deg/sec) TO THIS POINT EQUAL TO THE CHANGE FROM THAT POINT TO (20 deg/sec). THAT POINT IS (17.5 deg/sec).

FOR (Sustained Turn Rate) AT WHAT POINT IS THE CHANGE FROM (20 deg/sec) TO THIS POINT EQUAL TO THE CHANGE FROM THAT POINT TO (25 deg/sec). THAT POINT IS (23.5 deg/sec).

Max Instantanious Turn Rate (MITR)

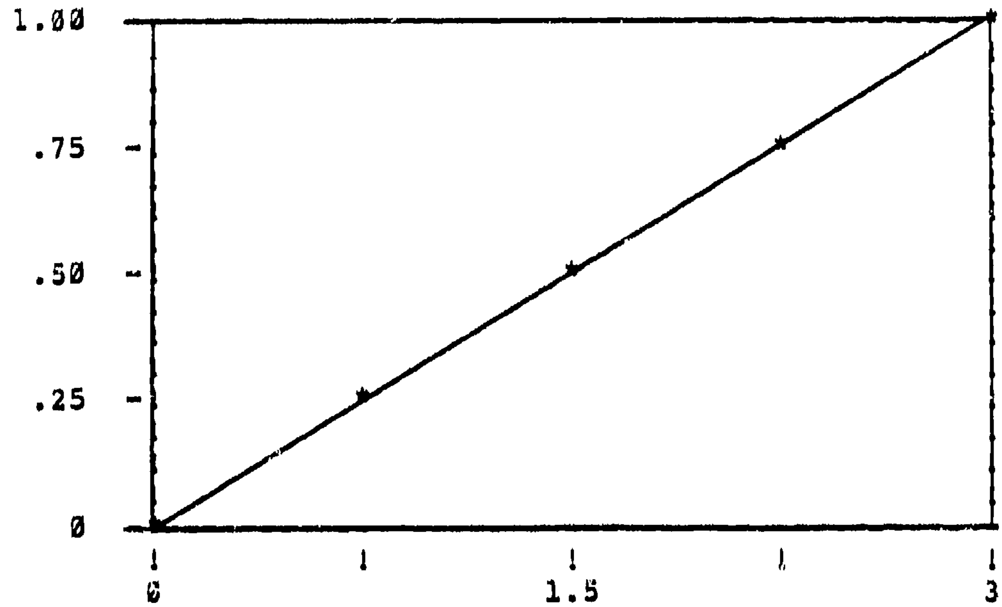


FOR (Max Instantanious Turn Rate) AT WHAT POINT IS THE CHANGE FROM(16 deg/sec) TO THIS POINT EQUAL TO THE CHANGE FROM THAT POINT TO (32 deg/sec). THAT POINT IS (25.5 deg/sec).

FOR (Max Instantanious Turn Rate) AT WHAT POINT IS THE CHANGE FROM(16 deg/sec) TO THIS POINT EQUAL TO THE CHANGE FROM THAT POINT TO (25.5 dg/sc). THAT POINT IS (21 deg/sec).

FOR (Max Instantanious Turn Rate) AT WHAT POINT IS THE CHANGE FROM(25.5 dg/sc) TO THIS POINT EQUAL TO THE CHANGE FROM THAT POINT TO (32 deg/sec). THAT POINT IS (29 deg/sec).

Projectile Cannon (PC)

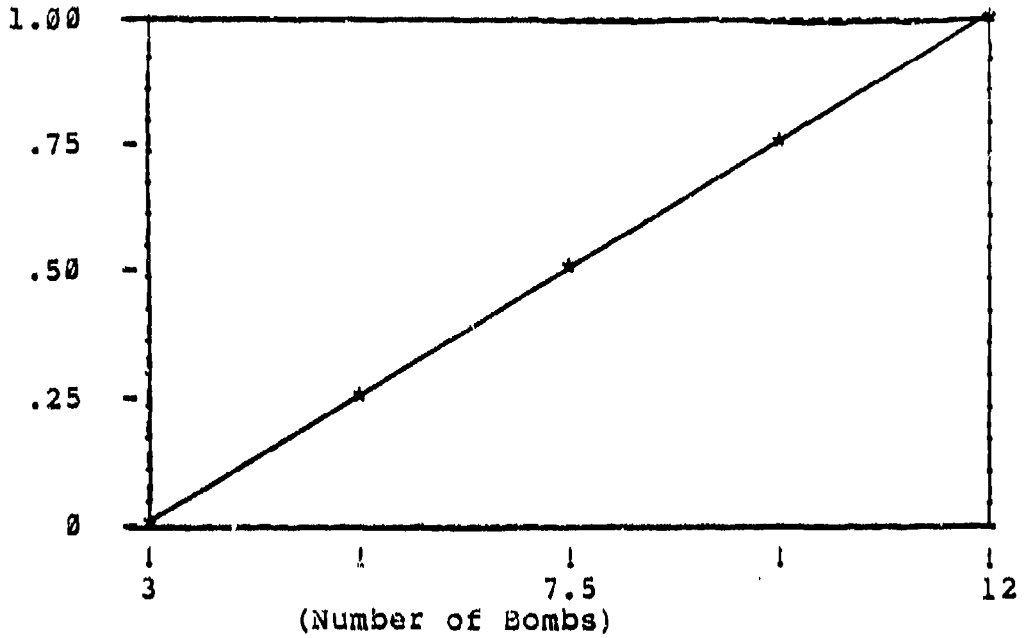


FOR (Projectile Cannons) AT WHAT POINT IS THE CHANGE FROM (0 Cannons) TO THIS POINT EQUAL TO THE CHANGE FROM THAT POINT TO (3 cannons). THAT POINT IS (1.5 cannons).

FOR (Projectile Cannons) AT WHAT POINT IS THE CHANGE FROM (0 cannons) TO THIS POINT EQUAL TO THE CHANGE FROM THAT POINT TO (1.5 cannon). THAT POINT IS (.75 cannons).

FOR (Projectile Cannons) AT WHAT POINT IS THE CHANGE FROM (1.5 cannon) TO THIS POINT EQUAL TO THE CHANGE FROM THAT POINT TO (3 cannons). THAT POINT IS (2.25 cannons).

"Smart" Bomb Capacity (SB)

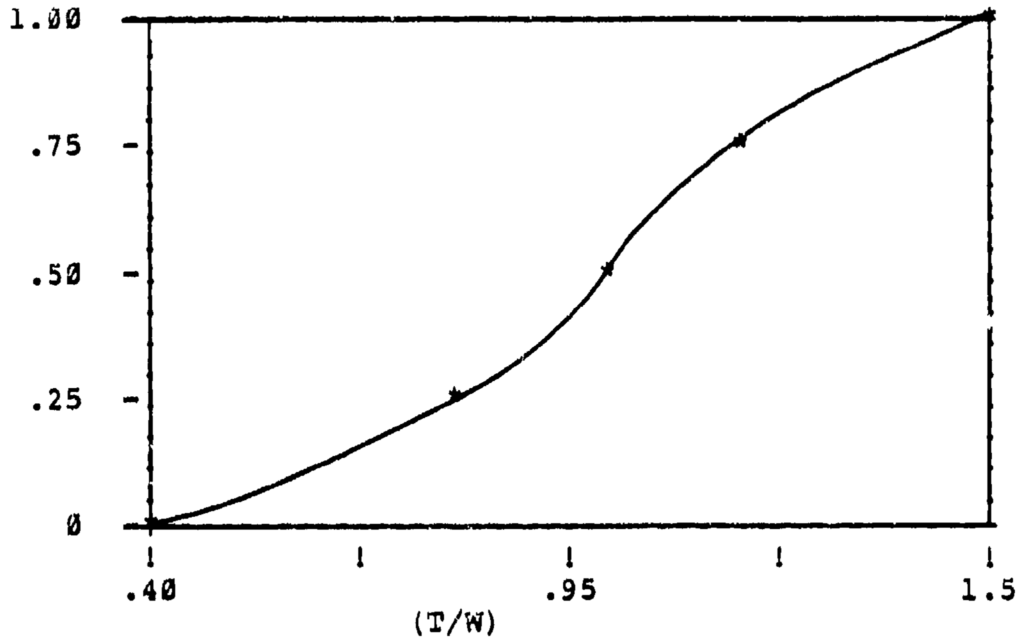


FOR ("Smart" Bomb Capacity) AT WHAT POINT IS THE CHANGE FROM (3 Bombs) TO THIS POINT EQUAL TO THE CHANGE FROM THAT POINT TO (12 Bombs). THAT POINT IS (7.5 bombs).

FOR ("Smart" Bomb Capacity) AT WHAT POINT IS THE CHANGE FROM (3 bombs) TO THIS POINT EQUAL TO THE CHANGE FROM THAT POINT TO (7.5 bombs). THAT POINT IS (5.25 bombs).

FOR ("Smart" Bomb Capacity) AT WHAT POINT IS THE CHANGE FROM (7.5 bombs) TO THIS POINT EQUAL TO THE CHANGE FROM THAT POINT TO (12 bombs). THAT POINT IS (9.75 bombs).

Thrust-to-Weight Ratio (T/W)

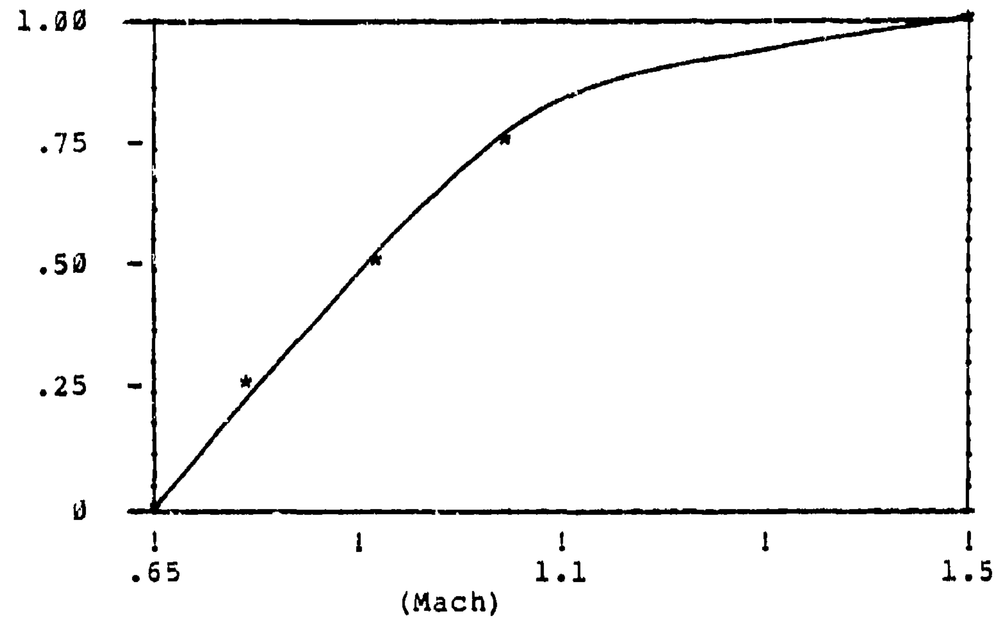


FOR (Thrust/Weight Ratio) AT WHAT POINT IS THE CHANGE FROM (.4 T/W) TO THIS POINT EQUAL TO THE CHANGE FROM THAT POINT TO (1.5 T/W). THAT POINT IS (.95 T/W).

FOR (Thrust/Weight Ratio) AT WHAT POINT IS THE CHANGE FROM (.4 T/W) TO THIS POINT EQUAL TO THE CHANGE FROM THAT POINT TO (.95 T/W). THAT POINT IS (.8 T/W).

FOR (Thrust/Weight Ratio) AT WHAT POINT IS THE CHANGE FROM (.95 T/W) TO THIS POINT EQUAL TO THE CHANGE FROM THAT POINT TO (1.5 T/W). THAT POINT IS (1.0 T/W).

Maximum Speed (MS)

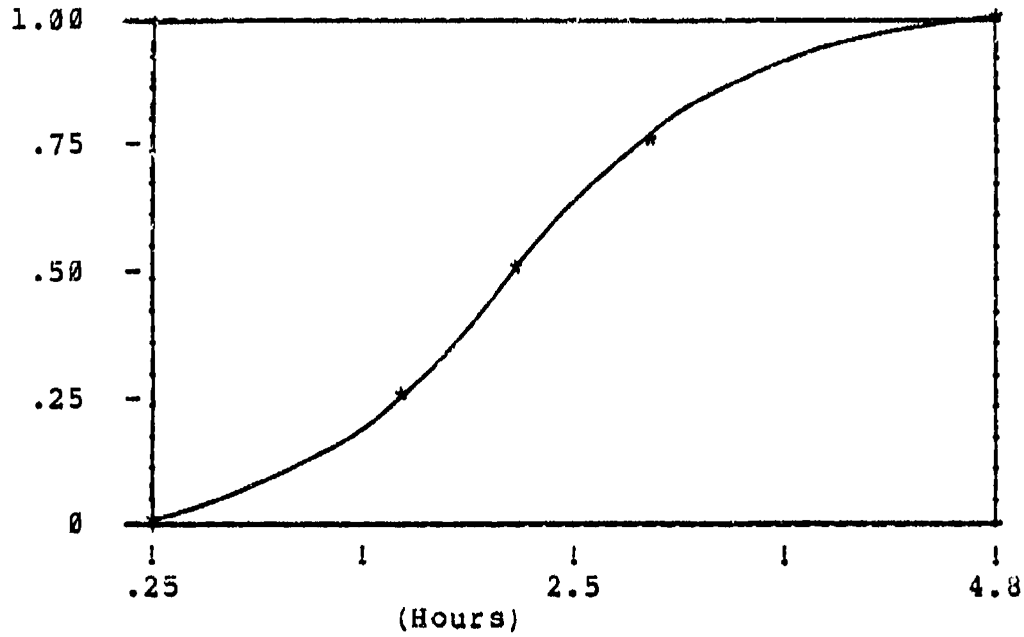


FOR (Maximum Speed) AT WHAT POINT IS THE CHANGE FROM (.65 Mach) TO THIS POINT EQUAL TO THE CHANGE FROM THAT POINT TO (1.5 Mach). THAT POINT IS (.90 Mach).

FOR (Maximum Speed) AT WHAT POINT IS THE CHANGE FROM (.65 Mach) TO THIS POINT EQUAL TO THE CHANGE FROM THAT POINT TO (.90 Mach). THAT POINT IS (.80 Mach).

FOR (Maximum Speed) AT WHAT POINT IS THE CHANGE FROM (.90 Mach) TO THIS POINT EQUAL TO THE CHANGE FROM THAT POINT TO (1.5 Mach). THAT POINT IS (1.0 Mach).

Total Loitering Time (TLT)

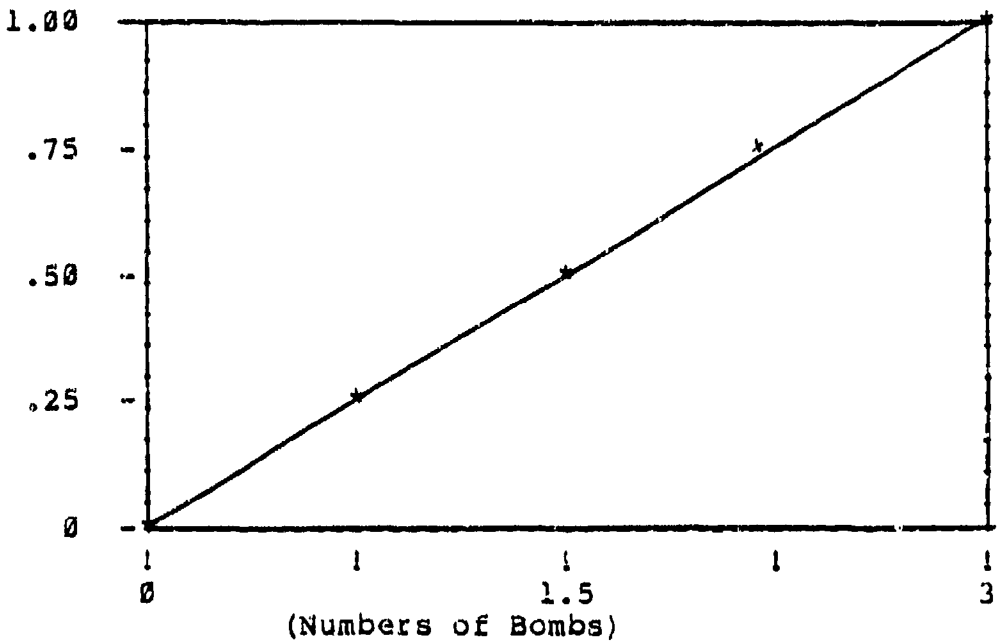


FOR (Total Loitering Time) AT WHAT POINT IS THE CHANGE FROM (.25 Hours) TO THIS POINT EQUAL TO THE CHANGE FROM THAT POINT TO (4.8 Hours). THAT POINT IS (2.5 hrs).

FOR (Total Loitering Time) AT WHAT POINT IS THE CHANGE FROM (.25 hrs) TO THIS POINT EQUAL TO THE CHANGE FROM THAT POINT TO (2.5 hrs). THAT POINT IS (1.5 hrs).

FOR (Total Loitering Time) AT WHAT POINT IS THE CHANGE FROM (2.5 hrs) TO THIS POINT EQUAL TO THE CHANGE FROM THAT POINT TO (4.8 hrs). THAT POINT IS (3.5 hrs).

"Dumb" Bomb Capacity (DB)

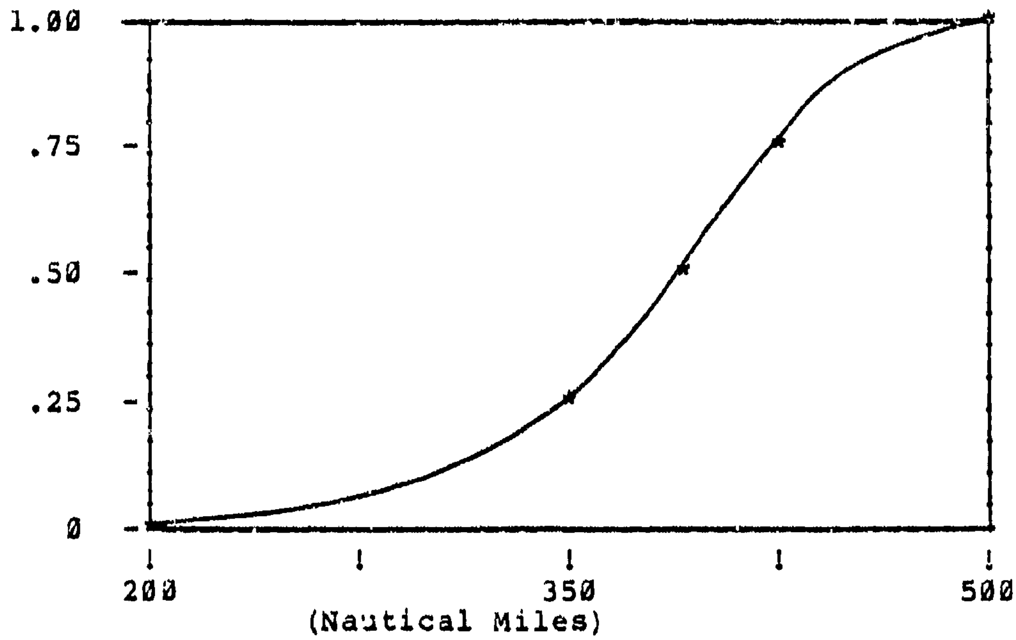


FOR ("Dumb" Bomb Capacity) AT WHAT POINT IS THE CHANGE FROM (0 Bombs) TO THIS POINT EQUAL TO THE CHANGE FROM THAT POINT TO (3 Bombs). THAT POINT IS (1.5 bombs).

FOR ("Dumb" Bomb Capacity) AT WHAT POINT IS THE CHANGE FROM (0 bombs) TO THIS POINT EQUAL TO THE CHANGE FROM THAT POINT TO (1.5 bombs). THAT POINT IS (.75 Bombs).

FOR ("Dumb" Bomb Capacity) AT WHAT POINT IS THE CHANGE FROM (1.5 bombs) TO THIS POINT EQUAL TO THE CHANGE FROM THAT POINT TO (3 bombs). THAT POINT IS (2.25 bombs).

Combat Radius (CR)

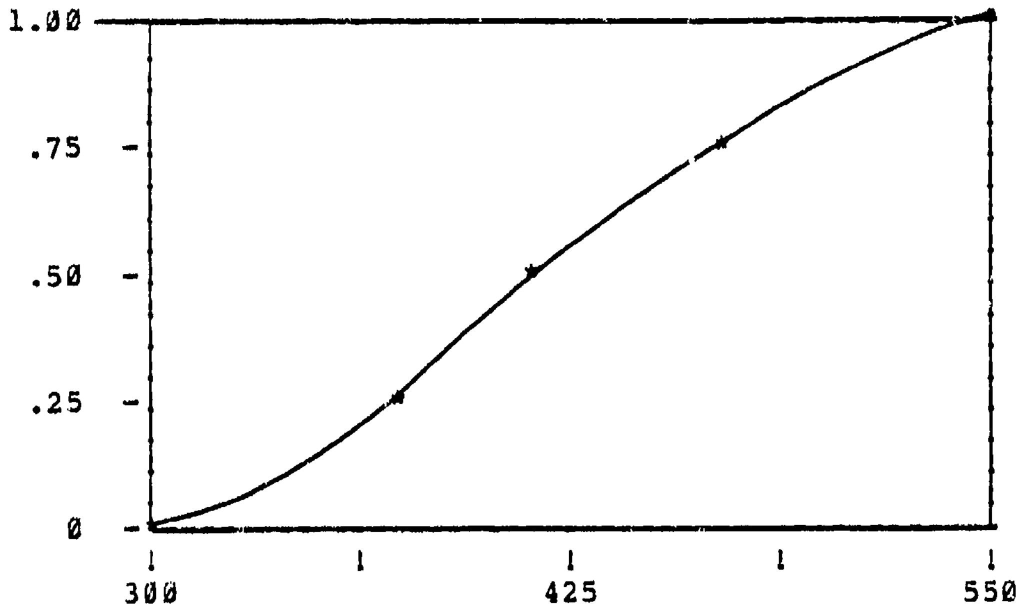


FOR (Combat Radius) AT WHAT POINT IS THE CHANGE FROM (200 Nm) TO THIS POINT EQUAL TO THE CHANGE FROM THAT POINT TO (500 Nm). THAT POINT IS (375 nm).

FOR (Combat Radius) AT WHAT POINT IS THE CHANGE FROM (200 nm) TO THIS POINT EQUAL TO THE CHANGE FROM THAT POINT TO (375 nm). THAT POINT IS (350 nm).

FOR (Combat Radius) AT WHAT POINT IS THE CHANGE FROM (375 nm) TO THIS POINT EQUAL TO THE CHANGE FROM THAT POINT TO (500 nm). THAT POINT IS (425 nm).

Inroute Sustained Speed (ISS)

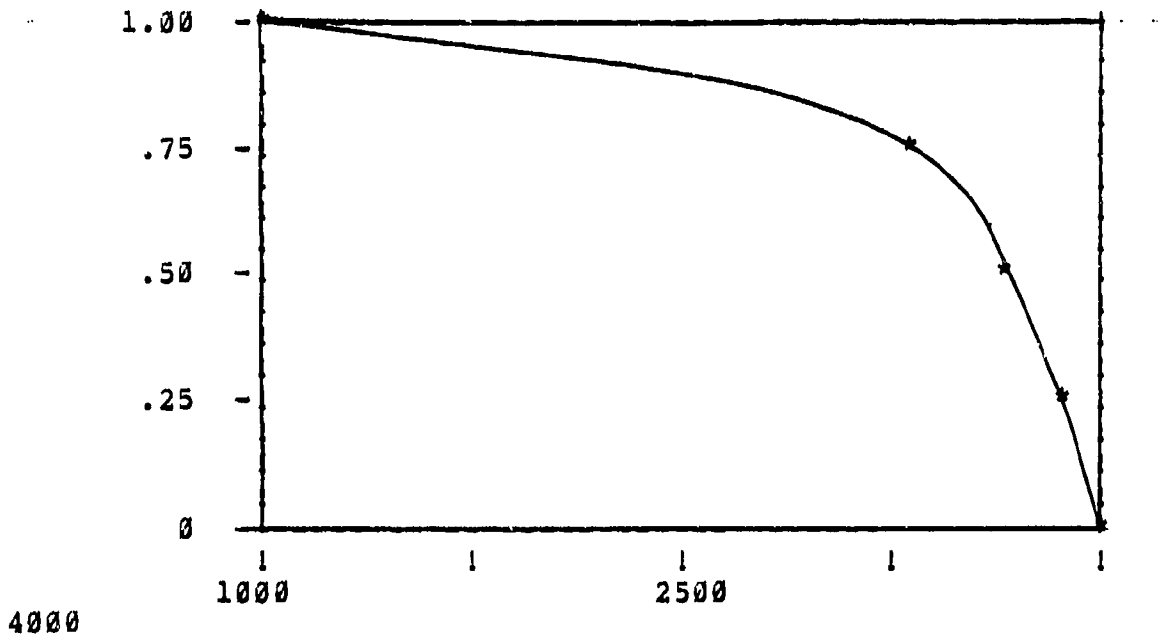


FOR (Inroute Sust. Speed) AT WHAT POINT IS THE CHANGE FROM (300 Nm/Hr) TO THIS POINT EQUAL TO THE CHANGE FROM THAT POINT TO (550 Nm/Hr). THAT POINT IS (400 nm/hr).

FOR (Inroute Sust. Speed) AT WHAT POINT IS THE CHANGE FROM (300 nm/hr) TO THIS POINT EQUAL TO THE CHANGE FROM THAT POINT TO (400 nm/hr). THAT POINT IS (410 nm/hr).

FOR (Inroute Sust. Speed) AT WHAT POINT IS THE CHANGE FROM (400 nm/hr) TO THIS POINT EQUAL TO THE CHANGE FROM THAT POINT TO (550 nm/hr). THAT POINT IS (475 nm/hr).

Combat Take-off Distance (TOD)

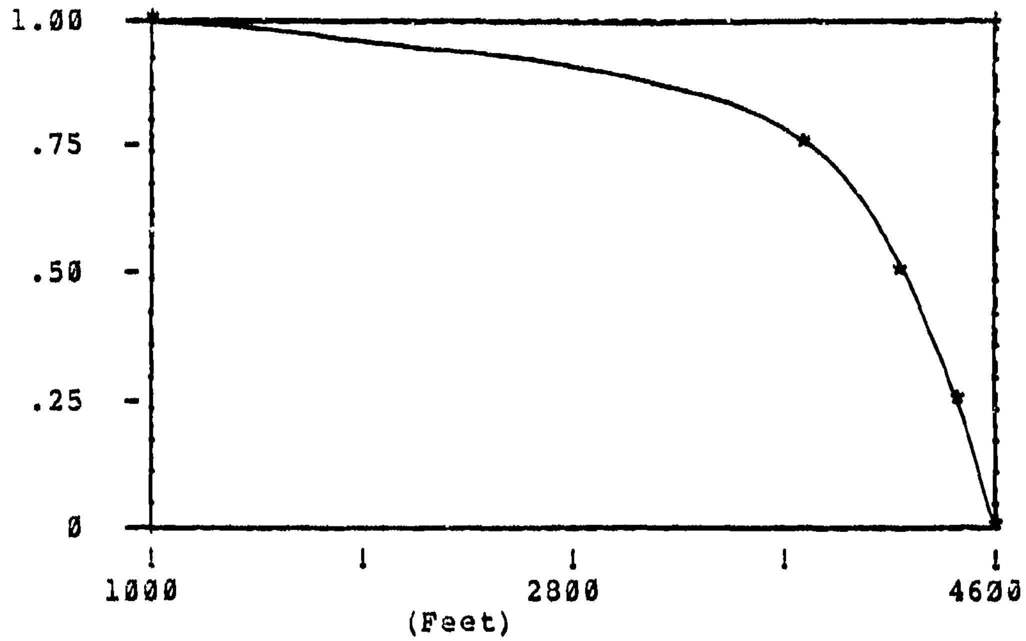


FOR (Take-off Distance) AT WHAT POINT IS THE CHANGE FROM (1000 Ft) TO THIS POINT EQUAL TO THE CHANGE FROM THAT POINT TO (4000 Ft). THAT POINT IS (3800 ft).

FOR (Take-off Distance) AT WHAT POINT IS THE CHANGE FROM (3800 ft) TO THIS POINT EQUAL TO THE CHANGE FROM THAT POINT TO (4000 ft). THAT POINT IS (3900 ft).

FOR (Take-off Distance) AT WHAT POINT IS THE CHANGE FROM (1000 ft) TO THIS POINT EQUAL TO THE CHANGE FROM THAT POINT TO (3800 ft). THAT POINT IS (3700 ft).

Combat Landing Distance (LD)



FOR (Landing Distance) AT WHAT POINT IS THE CHANGE FROM (1000 Ft) TO THIS POINT EQUAL TO THE CHANGE FROM THAT POINT TO (4600 Ft). THAT POINT IS (3800 ft).

FOR (Landing Distance) AT WHAT POINT IS THE CHANGE FROM (3800 ft) TO THIS POINT EQUAL TO THE CHANGE FROM THAT POINT TO (4600 ft). THAT POINT IS (3900 ft).

FOR (Landing Distance) AT WHAT POINT IS THE CHANGE FROM (1000 ft) TO THIS POINT EQUAL TO THE CHANGE FROM THAT POINT TO (3800 ft). THAT POINT IS (3700 ft).

Appendix B: Attribute Weight Questionaire

This appendix provides the questions, and answers obtained from the interview with Major Jack Shafer the DM. This information was used to develop the attribute weights.

Aircraft #1	Aircraft #2
10 Sustained Turn Rate	___ Sustained Turn Rate
32 Max Inst Turn Rate	16 Max Inst Turn Rate

What value of Sustained Turn Rate would make Aircraft #2 equal to Aircraft #1, given that all other attributes are equal between the two aircraft.

Answer 25 confidence +-.5

Aircraft #1	Aircraft #2
16 Max Inst Turn Rate	___ Max Inst Turn Rate
3 Projectile Cannons	0 Projectile Cannons

What value of Max Inst Turn Rate would make Aircraft #2 equal to Aircraft #1, given that all other attributes are equal between the two aircraft.

Answer 32 confidence +-.5

Aircraft #1	Aircraft #2
0 Projectile Cannons	___ Projectile Cannons
12 "Smart" Bombs	3 "Smart" Bombs

What value of Projectile Cannons would make Aircraft #2 equal to Aircraft #1, given that all other attributes are equal between the two aircraft.

Aircraft #1	Aircraft #2
3 "Smart" Bombs	___ "Smart" Bombs
1.5 Thrust/Weight	.4 Thrust/Weight

What value of "Smart" Bombs would make Aircraft #2 equal to Aircraft #1, given that all other attributes are equal between the two aircraft.

Answer 4 confidence +-1

Aircraft #1	Aircraft #2
.4 Thrust/Weight	___ Thrust/Weight
1.5 Maximum Speed	.65 Maximum Speed

What value of Thrust to Weight Ratio make Aircraft #2 equal to Aircraft #1, given that all other attributes are equal between the two aircraft.

Answer 1 confidence +-.05

Aircraft #1	Aircraft #2
.65 Maximum Speed	___ Maximum Speed
4.8 Total Loiter Time	.25 Total Loiter Time

What value of Maximum Speed would make Aircraft #2 equal to Aircraft #1, given that all other attributes are equal between the two aircraft.

Answer .9 confidence +-.2

Aircraft #1	Aircraft #2
.25 Total Loiter Time	___ Total Loiter Time
3 "dumb" Bombs	0 "Dumb" Bombs

What value of Total Loitering Time would make Aircraft #2 equal to Aircraft #1, given that all other attributes are equal between the two aircraft.

Answer 1.5 confidence +-.2

Aircraft #1	Aircraft #2
0 "Dumb" Bombs	___ "Dumb" Bombs
500 Combat Radius	200 Combat Radius

What value of "Dumb" Bombs would make Aircraft #2 equal to Aircraft #1, given that all other attributes are equal between the two aircraft.

Answer 3 confidence +-.1

Aircraft #1	Aircraft #2
200 Combat Radius	___ Combat Radius
550 Inroute Sust. Speed	300 Inroute Sust Speed

What value of Combat Radius would make Aircraft #2 equal to Aircraft #1, given that all other attributes are equal between the two aircraft.

Answer 500 confidence +-20

Aircraft #1	Aircraft #2
300 Inroute Sust Speed	____ Inroute Sust Speed
1000 Take-off Distance	4000 Take-off Distance

What value of Inroute Sustained Speed would make Aircraft #2 equal to Aircraft #1, given that all other attributes are equal between the two aircraft.

Answer 500 confidence +-25

Aircraft #1	Aircraft #2
4000 Take-off Distance	____ Take-off Distance
1000 Landing Distance	4600 Landing Distance

What value of Combat Take-off Distance would make Aircraft #2 equal to Aircraft #1, given that all other attributes are equal between the two aircraft.

Answer 2000 confidence +-100

Appendix C: Weapon System Management Information System (WSMIS) Fully Mission Capable (FMC) data for the F-15, F-16, and A-10 aircraft.

Percent F-15 FMC Status

Month:							
83/03	83/04	83/05	83/06	83/07	83/08	83/09	83/10
65.1	65.4	60.4	59.6	62.6	61.8	66.2	68.6

Month:							
83/11	83/12	84/01	84/02	84/03	84/04	84/05	84/06
68.7	67.8	71.8	75.1	71.6	72.8	70.8	71.8

Month:							
84/07	84/08	84/09	84/10	84/11	84/12	85/01	85/02
73.9	71.8	77.5	76.5	78.2	78.5	77.5	75.7

Average Percent FMC for F-15 (83/03-85/02) : 70.39%

WSMIS F-15 search constraints - AVISURS status history summary trend status hour rate by readiness category for F-15 within all commands at all bases.

Percent F-16 FMC Status

Month:							
83/03	83/04	83/05	83/06	83/07	83/08	83/09	83/10
64.2	64.1	65.5	68.0	69.9	66.1	70.9	71.4

Month:							
83/11	83/12	84/01	84/02	84/03	84/04	84/05	84/06
72.6	74.8	75.9	75.7	73.3	77.1	76.4	78.3

Month:							
84/07	84/08	84/09	84/10	84/11	84/12	85/01	85/02
77.7	77.7	80.2	78.3	77.7	80.9	80.8	80.2

Average Percent FMC for F-16 (83/03-85/02) : 74.07%

WSMIS F-16 search constraints - AVISURS status history summary trend status hour rate by readiness category for F-16 within 8 commands (AFE, AFR, ANG, ATC, LOG, PAF, SYS, TAC) at all bases.

Percent A-1Ø FMC Status

Month:							
83/Ø3	83/Ø4	83/Ø5	83/Ø6	83/Ø7	83/Ø8	83/Ø9	83/1Ø
76.2	74.9	75.9	75.2	75.5	74.6	72.9	72.6

Month:							
83/11	83/12	84/Ø1	84/Ø2	84/Ø3	84/Ø4	84/Ø5	84/Ø6
75.Ø	77.2	77.3	76.8	78.2	79.2	78.Ø	77.3

Month:							
84/Ø7	84/Ø8	84/Ø9	84/1Ø	84/11	84/12	85/Ø1	85/Ø2
77.8	79.5	81.Ø	8Ø.2	8Ø.6	8Ø.3	78.9	78.4

Average Percent FMC for A-1Ø (83/Ø3-85/Ø2) : 77.24%

WSMIS A-1Ø search constraints - AVISURS status history summary trend status hour rate by readiness category for A-1Ø within all commands at all bases.

Bibliography

1. Abel, Richard F. "Tactical Aircraft: Is greater quantity better that Superior Quality?," USAF Policy Letter for Commanders, Washington DC : U.S. Government Printing Office, 15 February 1981.

2. Analytic Sciences Corporation, The. Weapon System Management Information System Readiness Module D087A System/Subsystem Specification. Contract F33700-83-C-0076. Air Force Logistics Command, Logistics Management Systems Center, Wright-Patterson AFB OH, 15 April 1985.

3. BDM Corporation. "An examination of the Affordability of Increased Numbers of less Complex, Less capable Aircraft," Report No. BDM/W-80-847-TR, 2 January 1981.

4. Berry, Clifton F. Jr.,"The Revolutionary Evolution Of The F-16XL", Air Force Magazine, 66:50-55, (November 1983).

5. Blanchard, Benjamin S. Logistics Engineering and Management (Second Edition). New Jersey: Prentice Hall Inc. 1981.

6. Department of the Air Force. Cost Analysis: US Air Force Cost and Planning Factors. AFR 173-13. Washington DC : HQ USAF, 1 February 1984.

7. Department of Defense. Reliability and Maintainability, DoD Directive 5000.40. Washington DC : Government Printing Office, 8 July 1980.

8. Deputy For Development Planning, Aeronautical Systems Division, Air Force Systems Command. "Austere versus Capable Aircraft , Effectiveness Analysis: Interim Briefing." Wright-Patterson AFB OH, April 1981.

9. Deputy For Development Planning, Aeronautical Systems Division, Air Force Systems Command. "Quality Versus Quantity Issues." Wright-Patterson AFB OH, May 1981.

10. Deputy For Tactical Systems, Aeronautical Systems Division, Air Force Systems Command. "Derivative Fighter Evaluation Process. "Report to Brig Gen Richard E. Steere, Wright-Patterson AFB OH, 11 March 1982.

11. Ebersole, Douglas C., F-15 Performance Engineer. Personal Interview, ASD/TAEF, Wright-Patterson AFB OH, 13 June 1985.

12. Elbridge, Col Eaton P. "Let's Get Serious About Total Life Cycle Costs," Defense Management Journal, 13: 2-11 (January 1977).

13. Fallows, James. "America's High-Tech Weaponry" The Atlantic Monthly, 247:54-59 (May 1981).

14. Fink, Donald E. and others. "Military Stresses Maintainability and Reliability," Aviation Week & Space Technology, 113:42-81 (October 1980).

15. Janes's All the World's Aircraft 1983-1984. Janes Publishing Co. Inc. New York, 1984.

16. Johnson, Maj Herbert W. "Air Force Fighters: Simple or Complex?." Report 82-1285, Air Command and Staff College, Air University (ATC), Maxwell AFB AL, February 1982 (AD-B066 932).

17. Johnson, W. L. and R. E. Reel "Maintainability / Reliability Impact on System Support Costs, "Air Force Flight Dynamics Lab. Report No. AFFDL-TR-73-152. Wright-Patterson AFB OH, December 1973.

18. Keeney, Ralph L. and Howard Raiffa. Decisions with multiple Objectives: Preferences and value tradeoffs. New York: John Wiley & Sons, 1976.

19. King, Alwyn H. "Technology and the Balance of Power" Military Issues Research Memorandum, Strategic Studies Institute, US Army War College Carlisle Barracks Penn, 15 December 1977. (AD-A049 819)

20. Kniss, James R. "Developing Reliable Systems, Facts Versus Fiction," National Defense, 68: 24-27 (March 1984).

21. Lind, William S., "Quantity Versus Quality Is Not The Issue", Air University Review, 34:86-88 (September 1983).

22. Milton, Gen T.R.(USAF Ret.),"Lessons From Our Heritage",Air Force Magazine, 66:100 (August 1983).

23. Quade, E. S. Cost-Effectiveness: An Introduction and Overview. Rand Report P-3134. The Rand Corporation, Sanata Monica CA, June 1965.

24. Richie, Steven ., "An Eagle For All Arenas," Air Force Magazine, 66:43-49 (November 1983).

25. Rickett, Maj David E. Air Supericrity Concepts: 1980-2000. MS Thesis, US Army Command and General Staff College, Fort Levenworth Kansas, June 1981. (AD-B059 635)

26. Shafer, Maj Jack E. Tactical Air Command, Combat Analysis Branch, Personal Interview, TAC/DOP. Langley AFB VA, 20 June 1985.

27. Sullivan, Leonard Jr., USAF Consultant."Q3: The Quality / Quantity Quandary." Briefing given to Aeronautical Systems Division, Air Force Systems Command, Wright-Patterson AFB OH, October 1981.

28. U.S. Congress, House of Representatives, House Armed Services Committee Report, 99-166, 15 May 1979.

29. Yonika, Maj David P. A Multi-Attribute Value Theory Methodology For Selecting a Follow-On Close Air Support Aircraft. MS Thesis, LSSR 15-85. School of Engineering, Air Force Institute of Technology (AU), Wright-Patterson AFB OH, March 1985.

VITA

First Lieutenant David C. Merker was born on 23 September 1959 in Asbury Park, New Jersey. He graduated from high school in Middletown, New Jersey, in 1977 and attended Norwich University in Vermont, from which he received the degree of Bachelor of Science in Chemistry in May 1981. Upon graduation, he received a commission in the USAF through the ROTC program. He was employed as a computer operator for the International Flavors and Fragrances Corporation, Union Beach, New Jersey, until called to active duty in November 1981. He then served as a program manager for the National Emergency Airborne Command Post program for the Air Force Plant Representatives Office, The Boeing Company, Seattle Washington, until entering the School of Systems and Logistics, Air Force Institute of Technology, in June 1984.

Permanent address: 17 Walada Avenue
Port Monmouth, New Jersey 07758

AD-A162 238

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

1a. REPORT SECURITY CLASSIFICATION: UNCLASSIFIED

1b. RESTRICTIVE MARKINGS:

2a. SECURITY CLASSIFICATION AUTHORITY:

2b. DECLASSIFICATION/DOWNGRADING SCHEDULE:

3. DISTRIBUTION/AVAILABILITY OF REPORT: Approved for public release; distribution unlimited.

4. PERFORMING ORGANIZATION REPORT NUMBER(S): AFIT/GSM/LSQ/85S-23

5. MONITORING ORGANIZATION REPORT NUMBER(S):

6a. NAME OF PERFORMING ORGANIZATION: School of Systems and Logistics

6b. OFFICE SYMBOL *(If applicable)***:** AFIT/LSY

6c. ADDRESS *(City, State and ZIP Code)***:** Air Force Institute of Technology, Wright-Patterson AFB, Ohio 45433

7a. NAME OF MONITORING ORGANIZATION:

7b. ADDRESS *(City, State and ZIP Code)***:**

8a. NAME OF FUNDING/SPONSORING ORGANIZATION:

8b. OFFICE SYMBOL *(If applicable)***:**

9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER:

8c. ADDRESS *(City, State and ZIP Code)***:**

10. SOURCE OF FUNDING NOS.

PROGRAM ELEMENT NO.	PROJECT NO.	TASK NO.	WORK UNIT NO.

11. TITLE *(Include Security Classification)***:** See Box 19

12. PERSONAL AUTHOR(S): David C. Merker, B.S., 1st Lt, USAF

13a. TYPE OF REPORT: MS Thesis

13b. TIME COVERED: FROM ______ TO ______

14. DATE OF REPORT *(Yr., Mo., Day)***:** 1985 September

15. PAGE COUNT: 99

16. SUPPLEMENTARY NOTATION:

17. COSATI CODES

FIELD	GROUP	SUB. GR.
14	01	
12	02	

18. SUBJECT TERMS *(Continue on reverse if necessary and identify by block number)***:** Cost Effectiveness, Quantity, Quality, Reliability Fighter Aircraft, F-15, F-16, A-10

19. ABSTRACT *(Continue on reverse if necessary and identify by block number)*

Title: COMPARISON OF QUANTITY VERSUS QUALITY USING PERFORMANCE, RELIABILITY, AND LIFE CYCLE COST DATA. A CASE STUDY OF THE F-15, F-16 AND A-10 AIRCRAFT.

Thesis Chairman: John A. Long, Lt Col, USAF
Head, Dept of Cost Analysis & Pricing

Approved for public release: IAW AFR 190-1.
Lynn Wolaver
LYNN E. WOLAVER 21 Nov 85
Dean for Research and Professional Development
Air Force Institute of Technology (ATC)
Wright-Patterson AFB OH 45433

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT: UNCLASSIFIED/UNLIMITED ☒ SAME AS RPT. ☐ DTIC USERS ☐

21. ABSTRACT SECURITY CLASSIFICATION: UNCLASSIFIED

22a. NAME OF RESPONSIBLE INDIVIDUAL: John A. Long, Lt Col, USAF

22b. TELEPHONE NUMBER *(Include Area Code)***:** 513-255-6280

22c. OFFICE SYMBOL: AFIT/LSQ

DD FORM 1473, 83 APR EDITION OF 1 JAN 73 IS OBSOLETE.

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE

The primary emphasis of this research effort has been to investigate the quantity versus quality issue and to design a cost-effectiveness model to aid in evaluating it. This model incorporated mission effectiveness, readiness, and life cycle costs. The research effort was hinged around a case study comparison of the F-15, F-16, and A-10 aircraft. These aircraft were chosen because they represented varying system complexities and were used as surrogates to high, medium, and low complexity respectively. The comparisons made in this thesis were intended to demonstrate the usefulness of using aircraft effectiveness, readiness and cost data in a mathematical cost-effectiveness model.

The methodology that was followed, involved combining multi-attribute value theory, aircraft readiness data, and aircraft life cycle cost information. The result of this approach was a series of cost-effectiveness ratios, and a cost-effectiveness curve which incorporated the three close air support aircraft. The cost-effectiveness curve provided the costs, adjusted by both effectiveness and readiness values. The results of this research indicate that the approach used to develop the cost-effectiveness model does provide a quantitative way to evaluate the problem of quantity versus quality.